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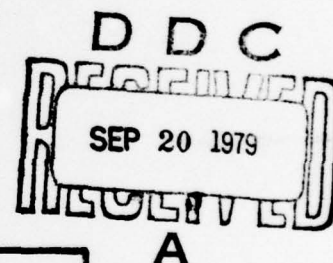
NAVAL POSTGRADUATE SCHOOL
Monterey, California

LEVEL

Master's

THESIS

DEVELOPMENT AND EVALUATION OF
CROSS-IMPACT ANALYSIS AS A
CRISIS DECISION-AID

by

Ralph L. Schindler

June 1979

189 p.

Thesis Advisor: R. Sherwin

Approved for public release; distribution unlimited.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Development and Evaluation of Cross-Impact Analysis as a Crisis Decision-Aid		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; June 1979
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ralph L. Schindler		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1979
		13. NUMBER OF PAGES 188
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cross-Impact Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Cross-Impact Analysis as a
Crisis Decision-Aid

by

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Lieutenant, United States Navy
B.S., United States Naval Academy, 1974

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS IN NATIONAL SECURITY AFFAIRS

from the

NAVAL POSTGRADUATE SCHOOL
June   1979

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Dean of Information and Policy Sciences

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ABSTRACT

This thesis reviews the decision-making dilemma caused by information uncertainty and ambiguity produced during crisis situations. Several cross-impact analysis techniques are reviewed and evaluated as possible crisis decision-aids. Cross-event analysis is selected and extended for demonstration in a hypothetical crisis situation involving South Asia. The selected technique is operationalized and employed in a controlled environment to assess policy response options to the hypothetical crisis. The thesis then assesses the technique's conceptual limitations, and evaluates its utility as a potential crisis decision-aiding methodology.

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I. DECISION-MAKING IN CRISIS SITUATIONS

A. INTRODUCTION

Accounts describing foreign policy-making indicate decision-makers frequently deal with profuse quantities of intelligence information; which may be inconclusive, ambiguous, or conflicting. In an analysis of the Pearl Harbor surprise attack, Wohlstetter reveals problems resulting from information quantity and unclear meaning. She characterizes the situation as one in which, "...the mass of signals grow increasingly dense and freighted with ambiguities." [Ref. 1, p. 3]. Sorensen points out that a recurring problem facing Presidents is that the facts concerning a situation "may be in doubt or dispute." [Ref. 2, p. 19]. Schlesinger highlights the ambiguity surrounding the 1963 Vietnam situation by observing that the President asked; "Were you two gentlemen in the same country?" [Ref. 3, p. 993], upon receiving two widely divergent situation assessments from two officials sent to Vietnam on a fact-finding mission. This story also demonstrates the important role individual perceptions play in decision-making.

Analysts suggest perceptions influence the decision process because decision-makers interpret information using their insights, expectations, experience, and goals. Sprout and Sprout refer to this as the "stateman's psychological environment (that is his image, or estimate, of the situation,

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setting, or milieu) [which] may or may not correspond to the operational environment" [Ref. 4, p. 318]. Perceptions are a key factor in recognizing crisis situations [Ref. 5]. Yet, it is in just such situations that information overloads and inconsistencies, which may confound a decision-maker's perceptions, seem to occur most dramatically [Ref. 6].

This chapter develops the concept that a "dilemma" exists in decision-making resulting from information overload and ambiguity. Establishing the dilemma's relationship to crises, and establishing its effect on the decision process requires introducing several relevant concepts. These include, identifying a basic decision process model, defining the concept of crisis, identifying its stress and information overload effects on decision-making, and examining factors which may reduce the dilemma. The purpose is to establish the need for a decision-aiding methodology which can lessen the dilemma's impact on the policy-making process.

B. THE DECISION-MAKING PROCESS

According to general decision-making theory, as developed by Turban and Meredith [Ref. 7], the first step in the decision-making process is problem identification.[1] The same

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[1]Subsequent steps include: searching for the alternative courses of action, evaluating the alternatives, and solution selection. These steps were not examined in detail but should be kept in mind during the discussion of the approaches to foreign policy analysis.

source suggests identifying problems through comparing desired and actual levels of goal attainment. This presupposes that organizational goals are explicit, and in a form which facilitates measuring their level of accomplishment.

Such a requirement may be met in product oriented organizations (capturing a specific share of the market, or obtaining a specific profit level) however, it becomes much more difficult in organizations which frame goals in terms of advancing or protecting the nation's interests.[2] Thus, in starting the decision process, the policy-maker immediately faces a problem using available information to determine what national interests an emerging situation threatens. The available information's accuracy greatly influences the precision of national interest identification and measurement.

Turbin and Meredith [Ref. 7] propose using an evaluation shceme in completing the decision process. The evaluation scheme requires some technique which predicts alternative response outcomes, a means of relating outcomes to goals, and a decision rule applicable to response selection. The authors also describe factors which complicate the decision process.

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[2]This problem directly relates to the requirement for a method of system monitoring which would be basic to a decision-aiding system. This aspect of the aid was not developed extensively in the current study due to its complexity and the time required to develop, and validate indicators. Significant research is being conducted in this area by C.A. McClelland and others in the Threat Recognition and Analysis Project [Ref. 8].

Complications develop in decision-making when incorpora-
ting multiple goals, evaluating an indefinite number of
alternatives, and determining how sensitive outcomes are
to changes in problem configuration. (Changes in problem
configuration could result from incomplete or inaccurate
information. These slight changes may alter a policy alterna-
tive's impact on overall situational outcomes, and require
an analysis of the sensitivity of the policy option's effect
to changing circumstances.) The above problems obviously
exist in the policy decision process. This study's major
premise is that an information processing dilemma, beyond
the range of these problems, further complicates policy
decision-making in a crisis situation. The characteristics
defining a crisis situation produce this dilemma.

C. THE CONCEPT OF CRISIS

Traditional international relations studies often ex-
plore the relationship between "crisis" and "normal" inter-
actions. These works, usually describing events surrounding
a crisis, give the concept several intuitive interpretations.
The most common among these view crises as marking "turning
points" in international relations. Other interpretations
describe crises as events which occur naturally within the system.[3]

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[3]In the Marxist-Leninist perspective, the occurrence of
international crisis is an expression of the process of world
revolution. Traditional power theory explains crisis as the
operation of the balance of power. Here, crisis results from
changes in the distribution of power, or from policy makers
applying "field-tests" to determine the status of the balance
[Ref. 9].

In his essay on "The Acute International Crisis," McClelland reviews these interpretations and concludes:

> The crises are thought to be connected
> with the international struggles for
> ideas and also for power. They are seen
> as indicators of the state of the
> international system, but are regarded
> as prime operations in the system as
> well. They seem to be related to going
> to war and to staying at peace. [Ref. 9, p. 188].

Obviously, crisis is a pivotal concept in international relations. The problem is to establish it as a distinct phenomenon with recognizable characteristics.

Recent theoretical approaches to international relations studies attempt to operationalize the concept of crisis. These approaches are examined in a later section developing the dilemma's impact on the policy decision process. The approach advanced by Hermann [Refs. 10 and 11] was selected as most relevant to the current study. He describes three dimensions which bound a crisis situation.

1. High Threat

The first dimension defining crisis arises because the situation poses "a potential hindrance or obstruction to some object or state of affairs that a decision-making unit is motivated to achieve." [Ref. 10, p. 29]. A situation that threatens important goals produces fear that failure to make a "good" decision could leave these goals in jeopardy. Having accurate and timely information, therefore, becomes extremely important. The other dimensions bounding the situation make it less likely such information is available.

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2. Short Response Time

Combining with the high threat factor is the realization that in a short period of time, if no action is taken, the situation may change in some major (unfavorable) way. This aspect requires reaching a decision quickly, allowing little time for collecting information. Furthermore, short response time does not permit establishing elaborate search routines to disclose alternative response options. Thus, information currently available forms the basis for the decision. While decision-makers may receive more information, its accuracy is questionable, and individual perceptions become more important in determining what policy actions are eventually taken. The third dimension limits the stored information's utility.

3. Surprise

This final dimension results from the "absence of awareness on the part of policy makers that the situation is likely to occur." [Ref. 10, p. 30]. This surprise aspect may stem from incomplete information, or result from a policy-maker's satisfaction with the situation, producing a reluctance to believe contrary reports. Surprise makes it unlikely advance preparations exist for coping with the situation, producing an "ad-hoc" decision process. Surprise also prevents serious data-collection which usually precedes significant anticipated events [Ref. 11, p. 416]. These characteristics produce a dilemma which inhibits effective crisis response.

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D. THE DILEMMA

In responding to a developing crisis, policy-makers face a dilemma dealing with breakdowns in what information usually means. As a crisis situation emerge, policy-makers receive unanticipated information inputs. These inputs are unexpected because they differ from perceptions concerning "normal" information outputs which the situation should be generating. Thus, the dilemma's first aspect involves understanding seemingly "unique" events. Policy-makers must correctly assess this information to realize that a problem exists, and to determine its importance.

As the crisis continues, more unique inputs flow in, increasing the information load the policy-maker must process [Ref. 12]. This aspect taxes the decision units' ability to sort and rapidly interpret available information.[4] Janis and Mann [Ref. 14] identify several compensating procedures individuals use in coping with information overload.

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[4]A large body of literature exists indicating that individuals are sub-optimal information processors. Fisher, et al. [Ref. 13] review the literature on individual's information processing abilities. Their report indicates that unaided human judgements in complex decision tasks are often less accurate than formal algorithms. For instance, evidence presented indicates that individuals are conservative in interpreting data due to misperception and misaggregation. This implies that decisions are normally based on a small number of information items, thus excess data and effort spent in its collection is "wasted". Other evidence, collected from "real-world" studies, indicates that decision-makers have difficulty using multiple cue information.
  The current study examines the way in which crisis situations further reduce decision-makers' capabilities to utilize information. The Fisher report indicates that the existance of the basic problem is enough to justify a decision-aiding system.

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Many of these inhibit the accurate evaluation of response alternatives.

Evaluation also requires dependable information. Unfortunately, information during a crisis may be inaccurate or conflicting due to source unavailability or distortion. Many factors might cause this distortion; however, the effect is to reduce useful information. The policy maker must discriminate between relevant and irrelevant; reliable and unreliable information. A crisis situation's high threat and time pressure components imapir the discrimination ability which information ambuiguity requires.

One of this study's central propositions is that: Policy-makers in a crisis situation must struggle to interpret large quantities of unusual data, having ambiguous or conflicting meaning. Because the situation involves high threat, the perception develops that the decision is crucial. The rapid event flows require accurate information evaluation, and allow a limited decision time. The situation's surprise characteristic precludes utilizing routine response measures. To interpret large quantities of ambiguous data the policy-maker must rapidly and efficiently focus all available information and expertise on the situation.

Reviewing current approaches to foreign policy analysis indicates that this dilemma affects the entire policy-making process. This review reveals the requirement for a real time decision-aiding methodology which can reduce the information dilemma's impact on policy formulation.

E. FOREIGN POLICY ANALYSIS

Traditional foreign policy studies developed the found-
ations for more systematic approaches in identifying threats
to national interests (crises). Hermann [Ref. 10] and
McClelland [Ref. 9] review the intuitive interpretations of
crisis found in descriptive international relations studies.
The early works these authors review describe crises as
"turning points" in international relations.

Crises were believed to result from competing national
interests, or as situations which developed from a series
of events a nation viewed as somehow posing a threat to its
interests. The effort to develop a more exact understanding
of foreign policy and crises produced two broad analytic
approaches. These approaches can be classified "systemic"
and "decisions;" both advance theoretical arguments and
research findings revealing the policy maker's dilemma.
Parker [Ref. 15] describes the tenets of these two approaches
and their major contributions.

A third approach stems from applying information theory
to foreign policy analysis, contributing new insights about
communications flows in policy-making. This technique
attempts to quantify concepts such as uncertainty and "noise."

1. Systems Approach

The systems approach views crisis as an indication
of the overall state of the system, directly related to

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system stability.[5] The connection to the traditional intuitive interpretations is obvious. From this viewpoint it can be argued the occurrence of crises can be used to identify the emergence of a problem situation.

An alternative view of crisis in systems studies proposes that it is a prime operation in the system itself. This view utilizes March and Simon's bureaucratic process model [Ref. 17]. In this model, organizations (modernizing societies) strive for stability in their environment. Recognizing a problem as having been dealt with previously, the organization tends to employ repetitive responses. As a result the organization establishes routine procedures whenever possible. Crises, in this model, are complexes of events overflowing normal processing channels, forcing new outputs, which return to the environment producing new inputs until new solutions are found [Ref. 9]. This sequence demonstrates how information ambiguity and uncertainty impact the decision process.

2. Decisions Approach

The second major approach to foreign policy analysis suggests that a stimulus-response relationship exists between crisis and decision [Ref. 11]. This approach highlights

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[5]McClelland [Ref. 9] derives this interpretation from Hans J. Morgenthau's Politics Amoung Nations. Price [Ref. 16] proposes that system stability and decision unit flexibility combine to define the range of options decision-makers consider in a crisis situation.

the importance that decision-makers' perceptions play in responding to incoming data.[6]

The decisions approach identifies crisis as a situational variable affecting the decision process in two ways. These result from crisis' stress inducing characteristics, and their impact on information processing. These factors are closely interrelated but, for reasons of clarity, are explored separately in this study.

Hermann [Ref. 10] proposes that crises are situations involving high threat, allowing short response time, and surprising the decision unit. Holsti [Ref. 6], and other authors [Ref. 14], present psychological evidence demonstrating that these characteristics are stress inducing.[7] The findings indicate that crisis induced stress reduces decision-making capabilities, especially those involved in identifying, sorting, processing, and interpreting information.

Foreign policy studies [Ref. 6], and field experiments [Ref. 10], give credence to these conclusions. These

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[6]Sprout and Sprout fully develop this concept in their works [Ref. 4 and 18]. Holsti, et al, [Ref. 5] modeled the process utilizing this factor. The model included: (1) the stimulus (meaning policy) applied by the initiating state, (2) the perception of the stimulus by the receiving state's decision unit, (3) the receiving state's policy response, and (4) response perception by the initiating state's decision unit.

[7]A high degree of threat to important values produces anxiety and overreaction. Long working hours required by short response times, and the perception of that pressure, magnify stress. Unanticipated, novel situations (surprise) are generally more threatening to decision-makers [Ref. 6].

findings indicate that policy makers face a dilemma inter-
preting and using information throughout the entire decision
process. Finally, indications are that stress is self-
reinforcing, suggesting that the dilemma increases as the
situation continues [Ref. 6].

These studies reveal how stress affects the decision
process by reducing the decision unit's ability to process
information. One study went further and examined informa-
tion volume produced during the crisis leading to World
War I [Ref. 6]. Holsti's findings indicate that both infor-
mation flow and uncertainty rose during the pre-war period.[8]
This increases both stress and information overlaod [Ref. 14].

3. Information Theory

Using information theory in foreign policy analysis
is a relatively new approach which clarifies the relation-
ship between uncertainty and stress. It measures information
levels and uncertainty contained in transmitted messages.
Studies using this technique report findings which relate to
interpreting incoming intelligence information.

Lee [Ref. 21] explains information measurement, and
demonstrates that "noise" in the system produced by erroneous

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[8]Other studies have explored the role of uncertainty
in the occurrence of war. Singer, et al. [Ref. 19] conclude
that the changing role of uncertainty accounts for the differ-
ent time spans for which their models predicted the occurrence
of conflicts. An attempt to formalize the procedure used
in the Singer study demonstrated the potential importance
of uncertainty in the decision process [Ref. 20].

or conflicting information reports significantly reduces a message's information value. McClelland [Ref. 22] uses information theory in developing a measure of uncertainty, which he employed in studying the Berlin question. This value represents uncertainty levels present in a given situation. This uncertainty reflects analysts' efforts to respond to the other side's actions. Uncertainty, measured in terms of H-Rel values, increased fairly sharply during "obvious" crisis phases in the Berlin problem.[9]

These findings demonstrate that policy decisions are made under uncertainty and increased information volume. This situation strains the decision-maker's ability to cope with an unfolding situation. Threat, time pressure, and surprise combine to increase stress, and further degrade decision-making capabilities.

The preceding discussion explored the information dilemma facing policy makers. This dilemma involved three aspects: (1) responding to unexpected information, (2) coping with increased information volume, and (3) interpreting ambiguous, conflicting reports. Because the dilemma reduces decision-making capabilities, the requirement exists for a decision-aid to reduce its impact on the decision process.

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[9]H-Rel is defined as the ratio of absolute uncertainty (some knowledge of performance) to maximum uncertainty (no performance data known). As this ratio approaches 1.00, it suggests that the behaviors have shown increasing signs of disorderliness, or indicates a large amount of "variety" in event emissions [Ref. 22, p. 172].

To be useful such an aid must perform several functions.

F. REDUCING THE DILEMMA

The problems of multiple goals, evaluating an indefinite number of options, possible slight changes in problem configuration, and the need to incorporate new information complicates the policy decision process [Ref. 7]. A useful decision-aid must, therefore, react to changing circumstances and incorporate diverse inputs.

Information relevant to a particular situation is often incomplete, outdated, or inaccurate. The decision-maker must, therefore, be able to draw on data other than information about the immediate situation [Ref. 11]. The perceptions and judgments of specialists in the field might be one source of such data. The decision-aid should focus specialists' expertise and knowledge to extract meaning from incomplete information.

A true decision-aiding system - as opposed to an information processing system - should help reduce the problem. It should facilitate problem identification, aid in enumerating options, and help determine their potential outcomes. It should also provide the means to evaluate outcomes, and indicate optimum responses.

The short response time inherent in a crisis situation requires rapid yet considered action. To reduce decision time and allow thorough evaluation, the decision-aid should

be computer adaptable. This capability would permit
obtaining interactions from numerous, geographically separate
analysts and specialists. It would also provide the capa-
bility for conducting sensitivity analysis, and hard copy
results for later analysis.

G.   OBJECTIVES

This research project will develop and evaluate a poten-
tial real time decision-aiding technique to examine policy
options for response in a crisis situation. A decision
analysis methodology which deals with alternative evaluation
under uncertainty will be selected as the basis for the
potential decision-aid.

After determining the methodology's information input
requirements, working assumptions, limitations, and alterna-
tive operation procedures, the methodology will be adapted
into a policy analysis format. Designing a policy analysis
format requires structuring the methodology to identify and
rank national objectives affected by a specific problem, to
identify possible response options supporting those objectives,
to determine each option's contribution to achieving those
objectives, and to evaluate their relative merit.

The modified technique will then be demonstrated in a
controlled environment. A study group, representing experts,
will be presented with a hypothetical crisis situation
in which the objective is to determine an effective response.
The technique will be used to guide the group in their
consideration of the problem, and to correlate their inputs.

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Based on this demonstration, the analytic technique will be evaluated on its effectiveness in structuring and obtaining a solution to the problem. The technique's utility will be assessed regarding its flexibility, ease of application, performance, and potential for computerization.

H. CONCLUSIONS

A crisis is defined by three "situational" boundaries [Refs. 10 and 11].

1. High threat to decision unit goals.
2. Short response time available.
3. Surprising the decision unit by its occurrance.

These dimensions impact the decision process producing three complicating factors which reduce a decision-maker's already questionable abilities [Ref. 13] to perform effectively when it is vitally important to do so.

These factors are [Refs. 6 and 22]:

1. Stress
2. Uncertainty
3. Information Overload

Increases in the levels of these factors, combined with poor information processing capabilities, produces a dilemma in interpreting information concerning a rapidly evolving situation.

This dilemma reduces the decision-maker's ability to:

1. Identify relevant useful data.
2. Correlate and interpret infromation.
3. Use this information to draw accurate inferences, and make responsible judgments.
4. Determine appropriate response alternatives, and evaluate their utility.
5. Make a logical solution selection.

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Reducing this dilemma to improve decision-making abilities requires a decision-aid which is:

1. Flexible enough to incorporate multiple goals, diverse options, and incomplete information.

2. Draws on the "stored information" of an expert's perceptions to interpret the situation.

3. Quickly focuses the expertise and knowledge of numerous specialists on a situation to evaluate possible responses.

4. Systematically evaluates alternatives and indicates an optimal response.

5. Is computer adaptable.

Subsequent chapters of this study will identify and examine an existing decision analysis technique, develop it into a possible policy analysis tool, demonstrate its application, and evaluate its utility.

II. CROSS-IMPACT ANALYSIS

A. INTRODUCTION

The previous chapter identified problems facing decision-makers operating in an environment characterized by uncertainty and ambiguous information. In a social or political environment, moving from problem awareness to effective control or corrective actions requires that decision-makers understand the complex relationships operating in the environment. Such understanding is inhibited when a problem's components are defined and related through imprecise concepts and incomplete theories.

As indicated earlier, social and political problems are not easily adaptable to systematic "scientific" analysis. In many cases, the problem elements are not adequately defined nor operationalized. Furthermore, no adequate theory exists which describes the complex relationships among problem elements and indicators. These difficulties are apparent in the attempts to construct theories, define variables, and identify reliable indicators for crises reviewed in Chapter One.

Socio-economic and political problems are defined using imprecise concepts based on a limited understanding of the relationships among the variables involved. For this reason, conducting systematic decision analysis requires an alternative approach to problem specification. The basis for one alternative approach is suggested by Helmer:

> ...we can either throw up our hands
> in despair and wait until we have an
> adequate theory enabling us to deal
> with socio-economic problems as con-
> fidently as we do with problems in
> physics and chemistry, or we can
> make the most of an admittedly unsat-
> isfactory situation and try to obtain
> the relative intuitive insights of
> experts and then use their judgments
> as systematically as possible.
> [cited in Ref. 23, p. 2]

The Delphi Technique was an early approach to employing
subjective judgments in problem evaluation. It was sub-
jected to several criticisms, one being that it produced
"linearly independent" estimates which failed to account
for potential interactions among the events being considered
[Ref. 24]. Cross-Impact analysis is a Delphi extension
intended to overcome this problem.

This chapter will present a non-technical explanation of
the fundamental notions underlying cross-impact analysis.
It will identify and classify contentious issues which must
be resolved before the technique can be used. This discussion
is intended to provide a basis for systematically comparing
the various approaches to conducting cross-impact analysis.
Specific areas which will be explored include: (1) the tech-
nique's basic concepts, (2) its information requirements
and their interpretations, (3) the computational procedure
used, and (4) the technique's outputs and possible applica-
tions.

In their review of the literature on decision-making,
Fischer, et. al. examine several decision-aiding technologies

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which use subjective estimates. These technologies follow

a "decomposition" approach involving six tasks:

        1.   Recognizing that a decision
              problem exists.

        2.   Identifying the possible
              courses of action.

        3.   Constructing a probabilistic
              model of the decision-making
              environment.

        4.   Constructing a model to eval-
              uate the possible consequences
              of each available action.

        5.   Selecting a course of action.

        6.   Implementing the alternative
              selected.
        [Ref. 13, p. 43-44].

Because steps 1, 2, and 6 involve understanding the

creative and organizational processes inherent in decision-

making, most decision-aiding technologies concentrate on

steps 3, 4, and 5. As this study will show, cross-impact

analysis fits in well with these techniques.[10] Cross-impact

analysis is similar to other subjective techniques in that:

it develops an event set for defining the problem environment,

it constructs a probabilistic model of that environment, and

it uses the model to evaluate possible courses of action.

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[10]It should be noted that, on occasion, an entire commun-
ity's evaluation can "miss the mark". The recent events in
Iran provide an example. Reportedly the entire intelligence
community was surprised at the situation's rapid deteriora-
tion (two crisis dimensions) [Ref. 25]. A large body of
psychology and organizational information processing litera-
ture addresses the causes of this phenomenon. These causes
are outside this study's scope, which attempts to develop
and evaluate an aid for reducing the information dilemma.

B. THE CONCEPT

   Cross-impact analysis is a technique which attempts to
identify a given situation's possible outcomes by quantifying
the linkages between potential developments. This is accom-
plished by systematically assessing how any particular event
impacts all other relevant events. The technique and its
various applications are based on the realization that most
events are connected in some way [Ref. 26]. As explained
by Gordon and Hayward: "it is hard to imagine an event
without a predecessor which made it more or less likely or
influenced its form - or one which, after occurring, left
no mark." They term these possible interrelationships "cross-
impacts" [Ref. 26, p. 101].

   A second principle behind this technique is, that due
to the nature of the "inexact sciences", the only possible
approach to quantifying these interrelationships is to
employ an expert's subjective judgments as a "substitute
for the exact laws of causality found in the physical sciences."
[Ref. 24, p. 134]. When the technique is employed, estimates
are obtained for three event aspects hypothesized to govern
possible interactions among future developments: (1) Mode -
whether an event "enhances" or "inhibits" another; (2) Strength -
how strong an impact one event has on another; and (3) Time
Lag - how long before an event's influence is felt by other
events. These aspects are developed in Gordon, Enzer, and
Martino [Refs. 26, 27, and 28]. While latter cross-impact
approaches do not assess these aspects explicitly, understanding

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the interaction concept is important to understanding the intention and approach behind the analysis.

As a corollary to using subjective estimates, group opinions are usually obtained on the basis that: "The accuracy of a group judgment is always greater than (or at least equal to) the average accuracy of the individual judgments." [Dalkey, cited in Ref. 29, p. 140].[11] Fischer, et. al. report several other studies which support this conclusion [Ref. 13, p. 50].

C. REQUIREMENTS FOR CONDUCTING CROSS-IMPACT ANALYSIS

To develop a probabalistic model of the problem environment using cross-impact analysis requires that four procedures be accomplished. The first three encompass the subjective estimation process and include: (1) specifying an event set which defines the environment, (2) estimating the initial occurrence probabilities of those events, and (3) estimating their interactions with each other (or their cross-impacts). The final procedure manipulates the model formed by these estimates to produce the data with which possible courses of action are evaluated. This step requires (4) developing an algorithm to use in the manipulation process. These procedures will be explained in detail below.

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[11]There are a number of subjective measurement techniques which depend upon aggregating group estimates. Subjective measurement, aggreation procedures and applications are disdussed in Torgerson, Miller, and Coombs [Refs. 30, 31, and 32]. The commonly used, group-based subjective measurement techniques rely heavily on central tendencies (i.e., means and standard deviations) in order to determine judgmental scores.

1. Event Set Specification

The first process undertaken in cross-impact analysis is developing an event set. This is "a set of possible events which are thought to be important to the issue being explored" [Ref. 33, p. 33]. The event set may be obtained in any manner: delphi, conferences, literature searches, consultations with experts, analyst specification, and so forth. A single event may address any subject, and the entire set may address any combination of subjects such as, "potential technological developments, a list of social or political developments, a combination of these, or something entirely different." [Ref. 34, p. 344].

As broad and loose as these requirements may seem, the means by which the event set was formulated in several of the demonstrations discussed in this study has been criticized as faulty [Ref. 29, p. 137]. Therefore, it seems relevant to review recommendations for accomplishing this process.

Enzer suggests candidate events be developed from the likely consequences of inaction, or allowing the "status-quo" to continue [Ref. 27, p. 50]. He also proposes several criteria for including candidate events in the analysis:

> (1) the development must be important to the subject being evaluated, in the sense that the event should have some impact on an action or a decision that is being contemplated.

> (2) only those important developments whose outcome is uncertain (that

is, those that may occur as
opposed to those that almost
certainly will or will not occur)
should be included in the set
being analyzed.

    (3)   if the event set is to be highly
limited it is also desirable for
the items to be causally re-
lated to each other in some
way. [Ref. 35, p. 345][12]

    (4) Developments or events as referred
to here denote specific items
which may occur in the future.
They are 'specific' in the
sense that their occurrence
or non-occurrence can be
rigorously determined.
[Ref. 27, p. 50].

       Mitchell and Tydeman propose several rules for event

formulation. Their purpose is to reduce possible respondent

misinterpretation and thereby reduce response variation.

These rules will be followed in the application section of

this study.

    (a)   Except where the cause is part
of the event to be studied,
events should not be stated in
the form 'A occurs because of B'.

    (b)   Events should be single rather
than multiple, i.e., 'A occurs'
rather than 'A,B, and C occur'.

    (c)   Events should, where possible,
be definite and specific rather
than vague and general, e.g.,'

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[12]Enzer develops the requirement of being "causally related"
through the concept of "coupling". He describes three types
of event coupling, "totally uncoupled", "coupled", and totally
included". Of these, totally uncoupled events are felt to
be of little importance in the analysis, coupled events
should be analyzed, and included events may be analyzed if
their impacts are not estimated more than once [Ref. 27, p. 52].

'Costs will increase more than
20% in real terms' rather than
'Costs will increase signific-
antly'. [Ref. 29, p. 136].

Formulation rules are necessary to insure that "the group
involved reach agreement and understanding on the specifica-
tion and wording of the event set." [Ref. 36, p. 333].

Although it is desirable that the event set completely
define the problem under consideration, this is rarely possi-
ble. The uncertainties in the problem environment, and the
complex issues involved could necessitate specifying many
events. Since the possible first order interactions between
events increases as the square of the number of events speci-
fied, estimating their interactions would quickly become
extremely time consuming [Ref. 34]. Therefore, completeness
is often obtained by fiat.[13] Since it is almost impossible
to specify an event set which includes every conceivable
development most analysts limit the event set to a manage-
able size and attempt to include the most important or signi-
ficant events. In such cases, events to be included in the
analysis are selected from a large list of "candidate" events
on the basis of subjective importance, desirability, or
impact ratings. These procedures will be described in the
next chapter.

_____

[13]This limitation's implications have been examined in
several cross-impact approaches. The developers (Enzer, Turoff,
and Mitchell and Tydeman) suggest different methods to iden-
tify the most important events and to retain the most sensi-
tive or influential ones for analysis. In this manner, it is
felt that the most serious aspects of a problem are considered.
Furthermore, it is always possible to expand the event set
as circumstances dictate. Thus, obtaining a complete event
set by "fiat" is felt to be the only practicable method,
and does not impose severe limitations.

2. Initial Probabilities

Once the event set is established and understood by the respondents, the next procedure obtains estimates for each event's "initial" likelihood of occurrence. These estimates are variously termed individual, initial or marginal probabilities.[14] All refer to a particular event's likelihood of occurring by some specified date.

As with event specification, Enzer suggests that these estimates should be developed from an environment which might evolve naturally from the current situation [Ref. 35]. This interpretation recognizes that developments are typically seen in their total environment, and not in isolation.

This viewpoint poses a conceptual problem with cross-impact analysis which must be resolved before the technique can be operationalized. If events are viewed in their total environment when their initial probabilities are estimated, do these estimates include a consideration of the occurrence of other likely events in the set? In other words, in estimating the initial probability that event A will occur, do respondents implicitly consider the impact on A of another event (say B) if the other event also occurs? Each approach to cross-impact analysis must deal with this problem, and

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[14]Different terms are applied by the various cross-impact analysis approaches to describe the technique's basic concepts. In this study these will be identified as they occur, and thereafter the most descriptive, or logically consistent term will be used.

it will be considered more fully while examining specific approaches.

A reasonable response to this problem appears to be that estimators do take the interrelationships among events into consideration, but only incompletely and not systematically. Therefore, some modification is necessary to obtain "consistent" estimates [Ref. 34, p. 342].

3. Cross-Impacts

The next process obtains "A qualitative description of the effect of the occurrence (or non-occurrence) of one event on the likelihood of occurrence of the other events in the set." [Ref. 27, p. 51]. These are subjective estimates concerning how an event's occurrence would change the probability of every other event's occurrence. These are binary estimates, dealing with the interactions between two events only.

In eliciting these estimates, respondents are told to assume certain occurrence (or non-occurrence) for an event and then assess its impact on each remaining events. Rules for event impact assessment state that the events are assumed to happen only once (i.e., non-repetitive), that they do not have to happen at all, and that they do not occur simultaneously [Ref. 36].

These estimates have been termed "conditional" or "causal" probabilities. This conflict in terms stems from another conceptual problem in cross-impact analysis, relating directly to the problem of obtaining consistent estimates.

The basic problem is determining how the cross-impacts should be interpreted. One interpretation is that the estimates are conditional probabilities in the "classical" sense (i.e., the probability of event A given event B has occurred, $P(A|B)$), or are used to derive conditional probabilities [Ref. 37]. Accepting this interpretation permits using Bayesian probability relationships to test estimate consistency. Several developers have derived conditions which are intended to insure consistency and can be used to compute probability bounds on subsequent estimates.[15] Another interpretation is that the estimates are causal, time-dependent probabilities to which classical probability rules do not apply (i.e., the probability A will occur assuming B occurs first, $P(A|B_f)$). In this case Bayesian probability relationships have only limited application [Ref. 39].

A third interpretation is that the technique attempts to obtain subjective estimates for the correlation coefficients between events. In this case inconsistency is not readily apparent, as when probability values exceed unity or become negative. Turoff applies this interpretation in his cross-impact approach [Ref. 36].

This problem will be examined in detail in the next chapter. Initially, however, it appears that using classical probability relationships not only permits testing estimates

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[15]See, for example, Dalkey and Sarin [Refs. 34 and 38] for consistency conditions and boundaries.

for consistency, but provides relationships for adjusting
inconsistent estimates, and furnishes a model for their
manipulation. Without such a model, and recognizing the
lack of causal knowledge in the social sciences, the tech-
nique faces problems in interpreting the subjective esti-
mates, and justifying the manipulation algorithms.[16]

4. Computational Procedure

The final cross-impact analysis process employs a
technique to analyze estimates and provide useful informa-
tion to decision makers. As noted by Dalkey, given the
large numbers of possible interactions,

> even if a matrix describing the inter-
> actions is available ... the task of
> thinking through the implications
> rapidly gets out of hand. Some com-
> putational aid is required to take
> account of the large number of inter-
> dependencies. [Ref. 34, p. 341].

Frequently, the approach conducts "a Monte Carlo
sampling of chains of events in which the probability of
an event in the chain is modified by the cross-impact of
the previously occurring event in the chain." [Ref. 34,
p. 341]. This procedure requires an algorithm for calculating
the cross-impact effects among events. Several methods of
manipulation and analysis have been proposed and are examined
in the next chapter.

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[16] It also seems that probability values imply that A and
B are discrete events; whereas correlation coefficients, "r",
imply that A and B are indicators of underlying variables to
which the events are linked conceptually within a theoretical
framework.

In the Monte Carlo process, an event is randomly selected, and its occurrence or non-occurrence randomly decided based on its initial probability. The remaining events' initial probabilities are adjusted using the selected algorithm, according to the first event's cross-impacts. At this point a second event is selected and decided, based on its new probability. The remaining probabilities are revised and the process continues until all events have been decided.

Completing the Monte Carlo procedure is termed a run. Conducting numerous runs permits calculating revised initial probabilities for each event based on the event's experimental frequency of occurrence. As an event is decided its occurrence of non-occurrence is recorded (either 1 or 0 respectively). Revised initial probabilities are then determined by dividing the number of times each event occurred by the total number of runs conducted.

Early research using the technique suggested conducting more than one thousand runs in order to reach stability and reduce random variation [Ref. 26]. However, during demonstrations as few as twenty runs produced adequate results [Ref. 27]. Johnson examined the requirements concerning how many runs were needed to produce significant probability shifts and stabilize inherent random variation [Ref. 40]. Using standard statistical techniques he concluded that: (1) The mean probability values for events reached stability within a small number of runs (< 50). This implies

that the model reached stability, or a consistent point, relatively quickly. (2) The standard deviations of modified probabilities decreased with increased numbers of runs. However, beyond fifty runs, the magnitude of these reductions was small. This indicates that stability was reached, and that random variation was only slightly reduced by increasing the numbers of runs. (3) As more events were included in the analysis set, no notable changes appeared in the average standard deviations obtained. This indicates that the numbers of runs does not have to increase as the number of events increases. (4) Furthermore, Johnson observed that while it is possible to obtain significant probability shifts from a statistical standpoint, there is no assurance that such shifts are significant from a policy standpoint [Ref. 40, p. 127-130].

D. CROSS-IMPACT ANALYSIS SYMBOLOGY

The different cross-impact approaches, besides using various terms to describe basic concepts, have also employed different symbologies in their demonstrations. This section is presented in an attempt to establish a consistent symbology for cross-impact computations. This will simplify comparing the different cross-impact approaches in the next chapter.

1. Event Set Specification

Let A, B, C, ... N be events which could develop from present circumstances, which seem to be related to each other (i.e., are coupled as previously described), and are

important to some problem being considered. These events
were selected and formulated in accordance with the rules
specified previously. Designating A as event one (E_1), B
as event two (E_2), etc., produces a set of events $\{E_1, E_2,$
$E_3, \ldots, E_n\}$.

2. Estimate Initial Probabilities

Each event $(E_1$ through $E_n)$ has an associated initial
probability of occurring by some specified time in the
future based on the present situation. It is possible for
experts to estimate this probability (i.e., if present
developments continue without change, the probability A, (E_1),
will occur by time T is x). Designate this probability (of
event A) as $P(E_1)$ and similarly for all events in the set
$\{P(E_1), P(E_2), P(E_3), \ldots, P(E_n)\}$. Or as P_i for i = 1,2,
3,...,n.

3. Estimate Cross-Impacts

The next step is to estimate the effect on the other
events of the occurrence of any one event (i.e., if event
B is certain to occur what is the new probability event A
will occur?). $P(E_1|E_2)$ or $P(i|j)$ for i,j = 1,2,3,...,n
and $j \neq i$. These estimates are obtained for each possible
event pair (i,j) and designated in the form P(impacted
event|certain event).

4. Computational Procedure

The result from this series of estimates may then be
arranged in an n by n matrix. Since the impact of an event
on itself obviously has no meaning, the diagonal cell by

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convention contains the events' initial probability. The matrix thus contains all n^2 required estimates.

FIGURE 1

BASIC CROSS-IMPACT MATRIX

the effect on
this event is

if this event occurs	EVENT	A	B	C	N
	A	$P(E_1)$	$P(E_2\|E_1)$	$P(E_3\|E_1)$	$P(E_n\|E_1)$
	B	$P(E_1\|E_2)$	$P(E_2)$	$P(E_3\|E_2)$	$P(E_n\|E_2)$
	C	$P(E_1\|E_3)$	$P(E_2\|E_3)$	$P(E_3)$	$P(E_n\|E_3)$
	N	$P(E_1\|E_n)$	$P(E_2\|E_n)$	$P(E_3\|E_n)$	$P(E_n)$

Note that $P(E_1|E_2)$ is not necessarily equal to $P(E_2|E_1)$.

The matrix is then manipulated using the Monte Carlo procedure previously described, or some other procedure may be substituted. Using numerous runs permits computing revised initial probabilities for each event based on its frequency of occurrence during the runs.

$$P'(E_n) = \frac{\text{\# times } E_n \text{ occurred}}{\text{\# runs conducted}}$$

E. OUTPUTS AND APPLICATIONS

This section will review the types of analyses conducted using the technique and their possible applications. The technique's proponents have demonstrated several types of

analyses using the data generated by the technique. Many applications claimed for these outputs seem to address effectively the difficulties identified with problem solving in the social sciences. These claims seem plausable in the context of the authors' arguments, however, final judgment on the technique's utility must be reserved until the claims can be verified with data from experiments or real world applications. These outputs and their supporting rationale will be described below, along with proposed applications. Specific procedures for conducting these analyses will be presented in the next chapter which develops the major cross-impact analysis approaches.

One often cited potential for the technique is the learning experience it provides. Due to its systematic approach, estimators are forced to develop and clarify their opinions regarding the causal linkages coupling potential developments in a field or several fields into a consistent picture [Ref. 33]. Estimators must be explicit when structuring their responses, and are forced to con- sider related impacts and overall consistency. This aids in organizing and evaluating an individual's views on a com- plex problem [Ref. 36].

Manipulating the matrix through the Monte Carlo process, or other procedures (other procedures will be discussed during the review of specific cross-impact approaches), pro- duces event sequence scenarios which indicate the various ways in which a given situation might evolve. As used in

cross-impact analysis the term scenario has a very specific

connotation. A scenario refers to the event outcome deci-

sion (either occurrence or non-occurrenc) made when the

estimates are manipulated, and the sequence in which the

events are decided. For a six event set a possible scenario

would be depicted in the following manner:

$$(1, 0, 0, 1, 1, 1,)$$

where events 1,4,5, and 6 occurred, and events 2 and 3 did

not. In this study, subsequent discussions of the cross-

impact methodology, of specific cross-impact approaches, and

of the study's demonstration results will use the term

scenario (or, event sequence scenario) to refer to these

event occurrence chains.

Scenario generation provides decision-makers a background

against which policy options may be evaluated.[17] By speci-

fying scenarios, and evaluating them using subjective event

importance ratings, it might be possible to identify obscure

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[17]Sarin discusses scenario generation and its importance
[Ref. 38]. For a set of n events there are 2^n possible
scenarios, each with an associated scenario probability,
$P(x_n)$. Sarin proposes a method for computing these scenario
probabilities from expert estimates. The scenario probabili-
ties may also be computed, as were the revised initial event
probabilities, through the Monte Carlo process. Each Monte
Carlo run produces one scenario, $P(x_n)$ for that scenario is
computed by the frequency that it occurs divided by the
number of scenarios generated.

$$P(x_n) = \frac{\# x_n \text{ produced}}{\# \text{ runs}}$$

However, this requires that many Monte Carlo runs be conducted.

but important situations from among the vast number of
possibilities [Ref. 33]. Used alone, scenario generation
at least indicates to decision-makers the likely consequences
of inaction. The scenario output is the technique's major
tool in its most interesting application, policy analysis.

Through comparing the scenarios (produced by recording
event sequence outcomes during a Monte Carlo simulation) to
the cross-impact matrix it is possible to identify "critical"
events which make a considerable difference in outcomes [Ref.
28]. This causal analysis also provides "a means of gaining
insight into key branch points and items on which current
actions and policies should be focused in order to increase
the likelihood of achieving a desired outcome." [Ref. 33,
p. 45].

By examining the cross-impact matrix with the scenarios
it is also possible to identify possible "side effects" pro-
duced by the decision under consideration. This examination
could aid the decision-maker in two ways. First, a nagging
problem which faces decision-makers is to identify additional
problems which may arise further down the line caused by
their attempts to respond to the immediate problem situation.
Determining a decision's possible side effects may reveal
unanticipated developments which might stem from a particular
situation or a particular policy option.

A second advantage offered by exploring a decision's
side effects is that the examination may indicate less
expensive means of attaining goals through investment in

high-payoff areas which may have seemed unrelated [Ref. 26, p. 101]. This advantage is reflected in attempts to use cross-impact analysis to evaluate resource allocation strategies. Gordon suggested resource allocation strategies could be tested by adjusting the initial probability estimates for one or several events to reflect policy decisions in order to improve or inhibit their likelihood. These adjustments are then manipulated as was the original matrix, and the output examined to determine the policy decision's effect on the various scenario probabilities observed [Ref. 24]. This process is termed sensitivity analysis, and can be used to explore the effects caused by changes in problem configuration.

Further cross-impact analysis applications derive from using the technique to model the relationships operative in a given situation [Ref. 4]. Enzer demonstrates that the matrix may be used to determine an event's dominance and sensitivity. In his approach, the sum of the absolute values in a matrix row can be interpreted as a measure of the magnitude of the impact one event's occurrence has on the occurrence likelihood of all other events (its dominance) [Ref. 27, p. 54]. As a minimum, this identifies the events which have the greatest and least effect, relatively, on the situation. Those events with the greatest overall effects are prime candidates for intervention through resource allocation.

Event sensitivity is computed from the algebraic sum of the matrix column values. This is a measure indicating how responsive an event is to the other events in the set [Ref. 27, p. 54]. It reveals events which may be susceptible

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to change through secondary intervention. It could also indicate those events which most readily indicate changes in the system, and hence, should comprise the components of a monitoring mechanism.

By focusing on the opinion spread registered by the experts, Enzer develops an uncertainty measure reflecting the degree of estimator uncertainty concerning the cross-impacts. This is derived for each event by determining the distance between the upper quartile and lower quartile estimate values [Ref. 27, p. 54]. This "uncertainty" measure also highlights the level of agreement among the experts, and can be interpreted as a "confidence" measure. Such information would be an aid in resource allocation, allowing decision-makers to avoid investing effort in influencing an event whose impact was highly uncertain. If subjective estimates regarding an event's importance and desirability are obtained with the probability estimates more elaborate analyses are possible. These could aid decision-makers in identifying desirable actions and areas warranting further investigation [Ref. 27, p. 57].

The cross-impact technique also appears amenable to manipulation with digraph theory, and other techniques used in studies of individual and organizational information processing (esp. information theory). Digraph theory uses binary matrix entries to trace third- and fourth-level interrelationships among events.[18] Turoff incorporated information theory

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[18]The principles and methods of digraph theory are presented in Harary, et al. [Ref. 42]. Axelrod [Ref. 43], and Bonham, et al. [Refs. 44 and 45] have attempted to apply digraph theory to international relations theory and problems.

in his cross-impact approach to relate estimates for
occurrence and non-occurrence [Ref. 36].

F. RATIONALE FOR SELECTING CROSS-IMPACT ANALYSIS

The preceding discussion has revealed several aspects of
cross-impact analysis which make it attractive as a decision-
aiding methodology for crisis situations. The technique's
advantages will be summarized below as justification for
selecting cross-impact analysis for demonstration and evalu-
ation in this project. Specific aspects of the technique
discussed include: (1) its subjective method of evaluation,
(2) its systematic approach, (3) its flexibility, (4) its
demonstrated application to policy analysis, and (5) its
potential utility as a learning tool.

1. Subjective

Using expert's subjective evaluations precludes the
need for a formal theory relating crisis elements, national
interests, and policy options. The procedure takes into
account the perceptions and accumulated knowledge of experts
and decision-makers (which is not easily transferred) and
uses them to process and interpret imprecise information.
It minimizes the need to collect precise data on numerous,
inadequately understood indicators, especially in situations
where time and stored information is limited.[19]

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[19]This is not intended to suggest that theory construction
and indicator development are not important. As noted in
Chapter One, these approaches are required for system moni-
toring, furthermore, they are necessary to achieve precision
in the social sciences as indicated by Rossenau [Ref. 46].
What is intended is to establish the current need for sub-
jective estimates in quantitative analyses of policy problems.

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2. Systematic Approach

Because the technique is systematic in its approach, it encourages the consideration of the numerous interactions which could be overlooked in situations involving short response time and stress. In addition, it proceeds logically from problem identification through the selection of policy options. The subjective estimates obtained during the evaluation process are retained so the entire analysis can be replicated at will, rather than being lost after the crisis has passed.

Finally, because it is a systematic procedure cross-impact analysis may be conducted using a computer. Most applications demonstrated, especially those presented by Mitchell and Tydeman, Turoff, and Sarin [Refs. 29, 36, and 38], have utilized or advocated an interactive computer system for querying experts. This capability increases analysis speed and flexibility, both of which are desirable for a decision-aid in crisis situations.

3. Flexibility

Cross-impact analysis is not constrained by data requirements to evaluating only a few empirically quantifiable variables. The variables used in the technique are obtained from experts' perceptions concerning a specific problem. If, while obtaining subjective probability estimates, it becomes apparent some important aspect of the problem has been omitted it is possible to include it in the event set. This capability is particularly useful in analyzing a crisis situation involving uncertainty and incomplete information.

It allows the event set to be modified in response to changing circumstances. Such "last minute" modifications are possible because the values used in the analysis are subjective, and can be easily revised or expanded.

Using subjective judgments also permits the approach to address any problem for which an appropriate event set can be specified. This flexibility is evidenced by the broad spectrum of problems to which the technique has been applied.

4. Demonstrated Applications

Several cross-impact studies have been conducted in situations relevant to policy analysis. Heuer describes one such study in reviewing CIA efforts to use quantitative techniques to analyze policy relevant situations [Ref. 41]. The approach is future oriented and addresses the potential evolution of a current situation. Thus, cross-impact analysis attempts to be predictive, conducts sensitivity analysis, and indicates degrees of uncertainty. Other developers have applied the methodology to problems of evaluating transportation alternatives, population trends, and energy options [Refs. 26, 33, and 47]. Changing values and objectives are implicitly considered by using subjective estimates or may be explicitly stated in the cross-impact matrix. Finally, once the estimates' form and meaning are understood the procedure may be used by anyone. For these reasons, cross-impact analysis enhances the process of analyzing a situation and reaching a policy decision.

5. Learning Tool

Since respondent estimates can be retained, the technique can help close the feedback loop involved in assessing the direction in which a situation is moving. This can be accomplished by comparing estimates obtained over time $(T_1 - T_2)$. If a policy has been implemented between T_1 and T_2, then the comparison tests the policy's success.

By monitoring the emergence of cross-impact matrices over time, it might be possible to gain insight into how organizations structure their knowledge about the environment. Thus, a series of matrices, taken from a particular situation, might reveal some mechanics of organizational information processing.

G. EVALUATION CRITERIA

The preceding overview highlighted cross-impact analysis' potential applicability as a policy tool. However, the various conceptual problems identified here and by the technique's developers have produced several alternative cross-impact approaches, each advancing different methods to deal with the technique's conceptual problems, and leading to confusion regarding which variation of the technique is the best to operationalize.

Due to the confusion, selecting a variation for extension as a crisis decision-aid should be approached systematically using consistent evaluation criteria. These criteria should address each variation's primary components, including its assumptions, underlying rationale, and implications. Specific

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implementation problems should be evaluated by examining information requirements, computational procedures, and methodological approach. The goal is to select a practicable approach and develop it into a crisis decision-aid.

In developing consistent evaluation criteria, several considerations must be kept in mind. These stem from the characteristics defining crisis, and this project's time and computational resource limitations. Based on these considerations, discussed in the first chapter, the following criteria were formulated for comparing the various cross-impact approaches.

1. Is the event formulation scope adequate? This refers to the subject area addressed by the event set. In the intended analysis, events must cover such concepts as "national interests" threatened, and specific "policy options" available.

2. Can events be rated on importance/desirability? The need for such subjective estimates in sensitivity analysis and event set selection has been indicated. This refers to whether or not the specific technique includes procedures for obtaining and using such estimates.

3. What types of analysis can be performed using the technique?

4. Is the technique computer adaptable?

5. Are the estimated relationships clearly formulated? This refers to whether or not the procedure used to obtain estimates, and the questions asked, are understood by the respondents. Are the respondents asked for estimates they can reasonably be expected to supply?

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6. Are the estimates consistent, or can consistency
be obtained? This refers to the need for estimates which can
be manipulated using a systematic, rigorous, methodology.

7. What algorithm is used to manipulate the estimates?
This refers to the procedure by which the cross-impacts are
"taken into account" [Ref. 34, p. 342], and how it is structured.

8. Is the procedure logical/justifiable? This
refers to the assumptions made in adopting the algorithm, are
they reasonable and what limitations do they impose?

9. How is consistency obtained? This refers to the
computational procedure for checking consistency and revising
estimates into a consistent set.

10. How are scenarios generated? This refers to the
procedure used to develop event sequence scenarios, how complex
it is and whether or not it provides a ranking system.

11. How many estimates does the technique require?

12. What types of computation are performed? This
refers to the complexity of the calculations. Are they
algebraic, quadratic, differentials, or linear programs?

13. How many terms are involved in each formula?

14. How many separate calculations are required?
This refers to what computational steps are required for
estimate manipulation, checking consistency, scenario
generation and analysis.

These last four criteria are proposed in order to
identify an approach which can be demonstrated using limited
computational facilities. This study will replicate the

selected approach manually, therefore, the number and
complexity of estimates and computations must be kept to
a manageable number.

H.   CONCLUSION

This chapter has presented a broad overview of cross-
impact analysis, identifying its basic concepts and potential
applications. Since there are a number of alternative
approaches to implementing the methodology a set of evaluation
criteria was developed to use in selecting an approach for
operationalization. The next chapter will review the major
cross-impact approaches, select one for demonstration, and
extend it to deal with a crisis situation.

Subsequent chapters will discuss the implementation
procedure used, identify the problems encountered in opera-
tionalizing the selected approach, and present the demon-
stration results. In the final chapter, these results and
the implementation experience will be used to evaluate the
selected cross-impact approach's potential utility as a
crisis decision-aid.

III. THE MAJOR CROSS-IMPACT APPROACHES

A. INTRODUCTION

This chapter will identify and evaluate the major appro-
aches to cross-impact analysis using the evaluation criteria
developed in the preceding chapter. Four major approaches
will be described and discussed in terms of their basic
assumptions, procedures and outputs. In addition, three
ancillary approaches which were felt to be too complex for
demonstration will be reviewed briefly. The four major
approaches will then be compared using the evaluation cri-
teria, and one will be selected for demonstration and evalua-
tion as a possible crisis decision-aid. The selection pro-
cess will also highlight possible problems in operationalizing
the selected approach.

Demonstrating the selected approach in a hypothetical
policy relevant, crisis situation may require that it be
extended to address specific problems inherent in such
situations. These problems include short response time,
and evaluating specific policy options. Possible extensions
to cross-impact analysis will be developed once an approach
has been selected.

B. THE BASIC APPROACH (GORDON)

The concept of cross-impact analysis was introduced by
Gordon and Hayward in 1968 [Ref. 26]. As previously noted,
it was a partial response to one of the Delphi criticisms

[Ref. 24]. Its first application was in a forecasting game, developed for the Kaiser Corporation, which tested resource allocation strategies [Ref. 24].

1. Assumptions

Cross-impact analysis is based on two assumptions. In response to the Delphi criticism, the developers hypothesized that most events are connected in some way. Further, they felt that it is possible to estimate these connections subjectively as to mode (enhancing or inhibiting), strength (amount of influence), and time lag (length of time required for effect to be felt) [Ref. 26, p. 101-4].[20]

Given that linkages existed and could be estimated, the developers next addressed how the impacts worked, or how one event's occurrence $D_m,(E_j)$, changed a second event's $D_n,(E_i)$, occurrence probability. They assumed each event had some "individual" (inital) probability of occurring $P_n,(P_i)$, by a specific date. The change in probability $P'_n,(P'_i)$, caused by another event's occurrence was assumed to be a function of mode, strength, and time lag. However, an event's failure to occur (non-occurrence) was assumed to have no effect on the remaining probabilities.

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[20] These relationships are more complex than indicated here. Gordon realized that the "connections are subtle and vary widely in strength. [sic] Composed of at least two major elements; probabilities of feasibility (P_T) and pursuit (P_P)." [Ref. 24, p. 139].

Stated mathematically, they assumed: [Ref. 26, p. 104].

$$P'_i = f(P_i, M, S, t_j, t)$$

where:

f = function

M = estimated Mode

t_j = time in the future E_j occurs

S = estimated strength

t = time in the future for which probabilities are being estimated

The relationship between events was assumed to be quadratic [Ref. 26, p. 105],

$$P'_i = aP_i^2 + bP_i + c$$

By assuming known end conditions:

when $P_i = 0$ then $P'_i = 0$

$P_i = 1$ $P'_i = 1$

and if $t_j = t$ (no time lag) $P_i = P'_i$

And assuming the mode, strength, and time effects are linear [Ref. 26, p. 106]:

$$a = kS \frac{t - t_j}{t}$$

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where

$$k = \pm 1 \text{ (Mode)}$$

$$S = \text{number between 0 and 1 (smaller representing weaker effect)}$$

Therefore, in the inhibiting case,

$$-1 < a < 0$$

and enchancing

$$0 < a < 1$$

this produces:

$$P'_i = kS \frac{t - t_j}{t} P_i^2 + [1 - kS \frac{t - t_j}{t}] P_i$$

2. Procedure

This equation was demonstrated in two applications, a historical context and a futures context. In these demonstrations, the estimates were made by the experimenters. The historical problem examined the Minuteman deployment decision, the future problem examined transportation develop-ments in light of technological advances and changing societal attitudes [Ref. 26].

In both cases the procedure began by specifying relevant events and developments to be examined. These

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events were obtained through literature searches, expert interviews, and the analysts' own opinions.

The next step was to estimate the initial probabilities and occurrence dates for each event. An event matrix was then constructed, and the potential interactions between each event and every other event were estimated.

These estimates assessed both the interaction's mode and its strength. They were made by assuming one event was certain to occur, and then predicting its impact on each remaining event. These values ranged from -1.0 to +1.0, and made up the matrix body. Upon reviewing the individual event pair interactions certain "predecessor-successor" relationships were apparent to the experimenters. In the subsequent manipulation, events which had to be predecessors were evaluated first.[21]

A computer was programmed with the quadratic relationship and the "Monte Carlo" procedure used to manipulate the matrix. If an event was decided to occur, its impact was calculated from its cross-impacts with each other event using the quadratic equation, and the remaining events' initial probabilities were adjusted accordingly. If non-occurrence was decided then the remaining probabilities

---

[21]In the matrix, these relationships were indicated by appending a second digit to the interaction values. (0 = immaterial, 1 = likely predecessor, 2 = necessary predecessor) [Ref. 26, p. 107].

were not changed. The computer run was conducted one thousand times so that "revised" probabilities could be computed for each event based on its occurrence frequency [Ref. 26, p. 108].

3. Analyses Performed

Using this procedure, Gordon and Hayward demonstrated that four potentially useful analytical methods could be developed from the initial matrix. These were: (1) final probability rankings, (2) probability shifts, (3) tracing causal effects, and (4) scenario sensitivity analysis.

Ranking by final probability produced a possible event sequence outcome scenario. In the example this was felt to be logically consistent (plausable). However, the developers realized it was no more consistent than other possible scenarios. (Alternative scenarios could be obtained by recording the "decisions" made in each computer run using 0 for non-occurrence and 1 for occurrence.) [Ref. 26, p. 108].

The ranking by probability shift (difference between P_i and P'_i) was used to identify the events most affected by the suspected interactions. In other words: "the item [event] which had the highest probability shift could be expected to be the one most influenced by the external events depicted by the remainder of the list." [Ref. 26, p. 108].

In their forecasting analysis, the developers attempted to use the matrix to trace through the reasons

for an event's resulting probability shift. For example
they concluded that:

> Within the groups of items [events]
> describing future transportation
> modes, fast sub-surface trains
> showed the highest probability
> gain, suggesting that changing
> customer preferences, social
> customs, and technological
> innovations might favor this role.
> [Ref. 26, p. 113].

In essence, this is an elaborate way to state the
probability shift conclusion, and later cross-impact developers
would attempt to be more explicit in tracing causal effects.

The developers also used their model to examine the
potential effects of conscious policy decisions. Policy
decisions were interpreted as decisions to allocate re-
sources to making a particular event or set of events more
likely. Such a decision was reflected by arbitrarily raising
the initial probabilities for those events. The policy
decision's results were then indicated by manipulating the
matrix using the new initial values and comparing the
effects produced, on the event sequence scenarios, with the
initial run [Ref. 26, p. 115].

4. Critique

Gordon and Hayward recognized that their approach
had several weaknesses. These would be expounded upon by
later reviewers. The quadratic relationship had been selected
due to its intuitive appeal and for convenience, however,
the authors were not insistent that it be used. They
suggested that other possible forms be examined. Gordon

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and Hayward also recognized that there was little justifi-
cation for assuming mode, strength, and time lag acted
linearly. A logistic function was recommended as being more
appropriate. The assumed non-effect of non-occurrence was
felt to be an oversimplification which could be easily over-
come. Finally, in future applications the developers pro-
posed that estimates be obtained by a consensus-building
technique such as Delphi [Ref. 26, p. 115].

One of Gordon and Hayward's critics, Enzer, criticized
the quadratic adjustment assumption on the basis that it
arbitrarily restricted the possible domain of change in
P'_i. The greatest absolute change in P_i could occur only
when P_i = 50%. The quadratic did not allow;

> ... the occurrence of one event to
> have a large positive absolute
> impact on an event whose initial
> probability is very low, or a large
> negative absolute impact on an
> event whose initial probability
> is very high. [Ref. 35, p. 352].

He notes that although this appears to violate intuitive
thinking, it did prevent P'_i from reaching unity or becoming
negative.

Enzer also explained the limitations produced by
ignoring an event's non-occurrence. He felt that failing
to consider non-occurrence leads to ambiguity in defining
the initial probabilities. This is because any cross-impact
effects which may have been implicitly included in estimating
the initial probabilities are not removed. However, Enzer

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noted that it may be conceptually difficult to estimate the effect of non-occurrence [Ref. 27, p. 59].

In their estimation of the interrelationships, Enzer felt that Gordon and Hayward had not adequately defined the cross-impact factors [Ref. 27, p. 53]. This problem relates to how estimator responses should be interpreted, as discussed in the preceding chapter. Two other critics, Mitchell and Tydeman, indicated this problem's implications when they observed that Gordon and Harward's "...procedure contains no mechanism to ensure that basic pairwise probability relationships remained intact." [Ref. 29, p. 134].

The basic approach had other problems associated with its use. Dalkey points out that relative likelihoods for individual event sequences (scenarios) could not be assessed directly. This was because only binary interactions were considered [Ref. 34].

> To make scenario computation
> useful it will be necessary
> either to obtain estimates of
> higher order interactions or
> find a more logically correct
> assumption concerning them
> [Ref. 34, p. 350].

Another problem noted by Mitchell and Tydemand was that the approach lacked an uncertainty measure with which to evaluate the expert's opinions [Ref. 29, p. 134]. Also, as discussed in Chapter Two, Johnson challenged the assumption that probability shifts which were significant from a statistical standpoint could be assumed to be significant from a policy standpoint [Ref. 40].

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C. MODIFICATIONS TO THE BASIC APPROACH (ENZER)

In two successive cross-impact analysis applications Enzer attempted to overcome some of the problems discussed above [Refs. 27 and 33]. In his earlier work Enzer retained the basic method's approach to quantifying event interactions, to using a quadratic manipulation, and to ignoring non-occurrence. The major innovation was that he used the Delphi technique to obtain his event set and subjective estimates. This allowed him to extend the analyses he could perform [Ref. 27].

By using the Delphi technique Enzer was able to retain the estimators' opinion spread for each specific relationship examined. Opinion spread is defined as the range between the upper quartile and lower quartile response values, or one standard deviation above and below the mean value. With this information Enzer was able to conduct two analyses more systematically than Gordon and Hayward had. Enzer demonstrated that the mean response values could be used to identify dominant and sensitive events before their probability shifts were determined. In addition, the estimator's opinion spread could be used to indicate estimator uncertainty concerning the potential interactions.

An event's dominance was determined by summing the absolute values contained in a matrix row. Since these represented an event's impact on the other events, this measure was used to identify the events with the greatest overall impact. Event sensitivity was measured by algebraically summing the column values. These values represented

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the degree to which all other events influenced a single event's occurrence probability. This measure was used to identify the events which responded most readily to changes in the problem situation.

The opinion spread in a row indicates the estimator's uncertainty regarding how an event's occurrence impacts the other events. The opinion spread in a column indicates the uncertainty concerning how an event is affected by the other events [Ref. 27, p. 55].

In addition to the standard estimates, Enzer elicited respondents' opinions concerning each event's importance. He suggested that these importance ratings, in conjunction with the above measures, can aid in identifying desirable events for resource allocation, and for selecting events to be used in sensitivity analysis. In this case, an important event which is insensitive to the others would require direct intervention, sensitive events might benefit from indirect action, and highly uncertain relationships would require closer analysis and evaluation before a decision could be made [Ref. 27, p. 57].

Although it introduced an uncertainty measure, and permitted more exact causal analysis Enzer's approach suffered from many of the same problems associated with the Gordon and Hayward method. These recurring problems included: the use of the quadratic manipulation, ignoring non-occurrence, and determining how to interpret the respondent's estimates. Furthermore, the Delphi technique,

while extending the analysis, has some inherent problems.
Fischer, et. al. cite studies which suggest that the Delphi
technique (where individuals make estimates; receive anony-
mous feedback about the estimates of other group members;
and make additional estimates based on the feedback) is a
poor way to elicit expert opinion. The studies reviewed in
Fischer, et. al. indicate that the best procedure to elicit
expert opinion uses a slightly different approach. The
recommended procedure is to have the experts make individual
estimates; then, bring the group together and allow the
experts to discuss their estimates face to face; and finally,
have the experts make a second set of individual estimates
[Ref. 13, p. 55].

Enzer's second application introduced more fundamental
changes to the Gordon and Hayward method. Enzer abandoned
the quadratic manipulation, and introduced the concepts of
"likelihood ratios" and "constant change of odds" to handle
the procedure of manipulating estimates. In this approach,
estimates were elicited as changes in probability and non-
occurrence was considered. Enzer also attempted to resolve
estimate inconsistencies [Ref. 33].

1. Assumptions

Using an event's importance rating, it was possible
for Enzer to limit the number of events to be included in
the analysis. Selecting the most important events avoided
the necessity to specify the entire environment, thereby,

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simplifying the analysis. However, this increased the
complexity of the estimation process.

Interrelationships were estimated in terms of the
change in likelihood of one event (E_i) produced by another
event's (E_j) occurrence. This was defined as $P(i|j)$. The
effect of non-occurrence could also be estimated in the same
way, and was defined as $P(i|\bar{j})$. If this second estimate was
too dififcult for respondents to provide it could be calcu-
lated using a standard probability relationship [Ref. 33,
p. 38]:

$$P(i) = P(j)P(i|j) + (1 - P(j))(Pi|\bar{j}))$$

These values were then used to compute the likelihood
(cross-impact) ratio for each event pair [Ref. 34, p. 350]:

$$\lambda_{ij} = \frac{1 - P(j)}{P(j)} \times \frac{P(j|i)}{1 - P(j|i)}$$

This became the factor by which the initial occurrence
probabilities were multiplied when an event's occurrence
or non-occurrence was decided. Using this ratio expanded

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the domain of change possible for an event's initial
probability.[22]

        To track the many changes in probability produced
by the occurrence or non-occurrence of numerous events,
Enzer introduced the concept of "constant change of odds".
He stated:

> ... the judgment concerning the
> impact on Event A of the occurr-
> ence of Event B is independent of
> the exact probability of occurr-
> ence of Event A, and that when-
> ever Event A is preceded by the
> occurrence of Event B the change
> in likelihood of occurrence of
> Event A is known from the initial
> input. [Ref. 33, p. 41].

This means that once the interaction between two events (A
and B) has been estimated, its value is not changed if
another event (C) occurs before B and changes event A's
initial probability. As long as B occurs before A it will
impact A's current probability to the same degree that it
was believed to impact A's initial probability.

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[22]As Enzer explains in his earlier work:
    Changes in probability in the form of quanti-
tative ratios opens the domain to the widest
range of possibilities. Several of these
are presented in Figure 6 in a form comparable
with the previous figure. From Figure 6 it
can be seen that an event whose initial proba-
bility was 20% could, if impacted by an
event that increased its likelihood by a
factor of 20, be raised to 83%. When the
quadratic is used, the maximum positive impact
for an event with an initial probability of
20% is to raise it to 36%. [Ref. 27, p. 61].

Figure 5. Effect of cross-impact factors when
using quadratic equation
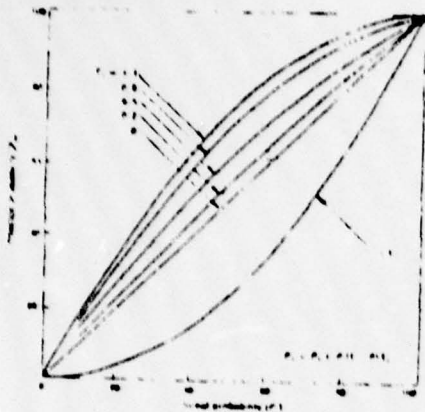
Figure 6. Effect of cross-impact factors when
using changes in likelihood

Initial probability (P_{in})
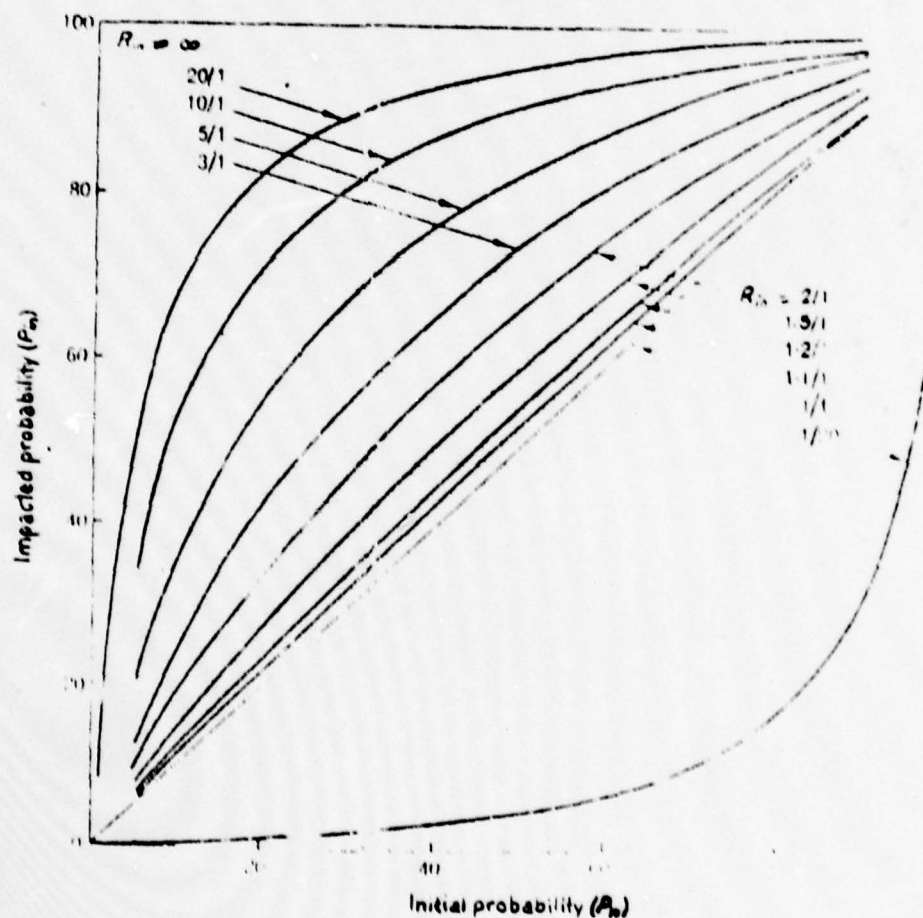
R_{in} Change in likelihood of event P_{n} produced by
occurrence of event(C_i)

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In order to assure pairwise consistency was maintained in the estimates Enzer adopted the following axioms [Ref. 33, p. 37]:

1. The initial probabilities of event pairs impose limits on the values of the impacted probabilities for that pair.

2. For any event pair, specification of the initial probabilities and one set of impacted probabilities (occurrence or non-occurrence) fixes the remaining set.

Thus, the relationship used to calculate non-occurrence could also be used to check for consistency. A simply boundary rule could then be applied to resolve inconsistencies. Pairwise consistency is required when dealing with probability estimates to insure the calculated probabilities do not exceed unity or become negative. Such values would be meaningless in probabilistic terms.

In applying this boundary rule Enzer assumed that the intention indicated by the respondents' estimates were correct, but that their actual values were incorrect. The boundary rule then makes the least adjustment required to restore consistency. For example, if a value given for $P(i|j)$ in conjunction with those given for $P(i)$ and $P(j)$ produced a computed value for $P(i|\bar{j})$ which was <0 or >1, then it was inconsistent. A computer would set the value of $P(i|\bar{j}) = 1$ or 0 as required, and recompute $P(i|j)$ [Ref. 33, p. 38].

2. Procedure

Enzer's approach followed the procedure developed by Gordon and Hayward. Candidate events for inclusion in the

analysis were obtained from a Delphi exercise. In order to limit the event set size, only those events considered most important (by subjective rating) were included.

The respondents were then asked to estimate each event's initial probability of occurring by a specified date, considering an environment which might evolve from the present circumstances without conscious human intervention to change the course of events. They were then asked to rate each event's desirability. This rating included two subjective estimates; the desirability of an event to the environmental aspect being considered (+ or -), and its impact on that environmental aspect should the event occur (0 = weak to 10 = strong) [Ref. 33, p. 46]. This desirability rating seems to relate to subjectively assessing whether an event enhances or inhibits policy goals, or whether an event influences a situation in a direction desired by the decision unit.

The respondents were next asked to assess the inter-relationships between events. They provided the new likelihood of occurrence for each event given each other event's occurrence (and non-occurrence if possible, otherwise this value was computed). The estimates were then checked for consistency and revised as necessary using the boundary rule.

Likelihood ratios were then computed to fill in the matrix, and the estimates manipulated as in the basic method, using a Monte Carlo simulation.

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3. Analyses Performed

With this approach Enzer was able to perform all the analyses permitted by the basic approach, including:

1. determining even sensitivity and dominance
2. scenario generation
3. exploring causal relationships
4. conducting scenario sensitivity analysis

In addition he had obtained an indication of respondent uncertainty using opinion spread. Rating events by desirability allowed selected events to be included in the sensitivity analysis. It also permitted choosing the more desirable events as subjects for testing resource allocation strategies.

Furthermore, desirability ratings provided criteria with which specific event sequence scenarios could be evaluated. Using these criteria, it was possible to determine which scenarios were the most desirable, and which strategies produced them.

4. Critique

This approach overcame several difficulties associated with the basic approach, specifically it

1. considered non-occurrence
2. eliminated the quadratic assumption
3. demonstrated that expert opinions could be used in analyzing complex situations
4. provided an uncertainty measure for evaluating estimates

Nevertheless, several problems still remain.

It was still difficult to identify significant probability shifts, although the desirability/impact and importance ratings had reduced the necessity for this determination. The interrelationships considered were still only binary, and even with desirability ratings it was still not possible to determine the most probable scenarios. Finally, it was still unclear what the respondents meant when they provided interaction estimates.

This last problem seems to have been, if anything, confounded by Enzer's attempt to introduce classical probatility relationships. As Mitchell and Tydeman observed:

> A fundamental difficulty with cross-impact analysis is to determine what respondents actually mean whn they answer the conditional probability questions normally posed. Results of studies currently in progress indicate that (1) participants are frequently confused and unsure of the interpretation of such questions, and (2) respondents often interpret the question in terms of time-dependent conditional probability statements, namely 'If event A occurred (first), what is the probability of B occurring?' [Ref. 29, p. 133].

In addition, introducing conditional probability relationships stimulated the use of classical probability theory in determining estimate consistency. Also, Jackson and Lawton observe that the classical probability equation used to calculate non-occurrence and test consistency could also be used to derive half the matrix entries once the other half had been specified [Ref. 37, p. 265].

Mitchell and Tydeman point out that, if the cross-impact estimates are interpreted as being time-dependent, Enzer's approach may not be valid.

> ... the standard observation that
> $P(A)P(B|A) = P(B)P(A|B)$ beomces,
> with the inclusion of time-dependence
> $P(A)P(B|A_{first})$ (=) $P(B)P(A|B_{first})$.
> In this restatement equality is not
> quaranteed - in fact, it would be
> pure coincidence other than when
> events A and B were independent.
> [Ref. 29, p. 135].

The consistency question led Enzer and Alter to address using Bayesian probability in cross-impact analysis. They suggested that confusion in interpretation was caused because the early approaches [Ref. 39, p. 231]:

1. Described future events with no real sense of time sequence.

2. Used a data collection technique which blurred the distinction between correlation and causality.

They concluded that conditional probabilities were not directly applicable to causal situations [Ref. 39, p. 237]. This conclusion also had been reached in 1972 by Turoff who proposed an alternative approach to cross-impact analysis [Ref. 36].

D. ASSUMED CONSISTENCY (TUROFF) APPROACH

Turoff attempted to accomplish several goals with his approach. One was to develop a method which could determine the causal impact of potential events not specified in the event set. He also wished to establish some relationship between an event's occurrence likelihood and the effort

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invested in either promoting or preventing the event.
In presenting his approach Turoff acknowledged that
because higher order interactions are difficult to esti-
mate, "we in effect ignore terms of P^2 or greater, hoping
that the three- or four-way interactions are small." [Ref. 36,
p. 326]. Nevertheless, Turoff did attempt to derive a
measure of the strength of these higher order interactions.

1. Assumptions

Turoff's approach was based primarily on the assump-
tion that:

> Given a set of evnets which may or
> may not occur over an interval of
> time, we assume that an individual
> asked to estimate the probability
> of occurrence of each event will
> supply a 'consistent' set of
> estimates [Ref. 36, p. 317].

This assumption effectively removed the requirement to
check estimate consistency. Instead estimates were obtained
using an interactive computer program. In this manner the
respondent was shown the results produced by his estimates,
and allowed to revise them at will until he felt the model
they produced met his expectations.

A second assumption in this approach is founded on
information theory, which is used to calculate cross-impact
factors (C_{ij}) from estimates used to derive values for the
effect of occurrence (R_{ij}), and non-occurrence (S_{ij}) for
each event. The assumption was that "if a correlation
exists between R_{ij} and S_{ij} is is such as to maximize the

added information." [Ref. 36, p. 324]. The effect of this relationship can be shown simply.

If ε is defined as a quantity close to 0 then [Ref. 36, p. 324),

$$\text{If } P_j = \qquad \varepsilon \qquad\qquad 1/2 \qquad\qquad 1-\varepsilon$$

$$\text{then } \frac{dR_{ij}}{dS_{ij}} = \qquad \varepsilon \qquad\qquad 1 \qquad\qquad 1/\varepsilon$$

$$\text{and } P_i = \frac{R\varepsilon+S}{1+\varepsilon} \approx S \qquad \frac{R+S}{2} \qquad \frac{R+\varepsilon S}{1+\varepsilon} \approx R$$

> This behaves physically as one
> would desire, for if P_i is close
> to one, then a very large change
> in R is necessary to make a small
> change in S. Conversely, if P_j
> is close to zero, a very large
> change in S is necessary to pro-
> duce a small change in R. Also
> when P_i = 1/2 the relative change
> in R and S is equal. [Ref. 36, p. 322].

Finally, a likelihood measure is used in expressing the probability that an event occurs, called its occurrence ratio (ϕ). This measure is similar to Enzer's likelihood ratio. Under assumed occurrence or non-occurrence it ranges from $+\infty$ to $-\infty$ [Ref. 36, p. 319]. The occurrence ratio is assumed to be directly proportional to a measure of effort, or [Ref. 36, p. 320]:

$$\phi P_i \propto E_i{}^T$$

where

$$\phi P_i \quad = \quad \text{the occurrence ratio of event i,}$$

and

$$E_i{}^T \quad = \quad \text{the total amount of effort expended in} \\ \text{either bringing about or preventing "i"}$$

Assuming that estimators are consistent, the assumed maximization of added information allows a difference equation to be used for cases in which new information is received (i.e., an event's occurrence or non-occurrence becomes certain) [Ref. 36, p. 318]. Assuming certain occurrence ($P_j = 1$), then, the approach defines $R_{ij} = P_i$, where R_{ij} is the probability of the ith event given that j is certain to occur. Turoff then derives a cross-impact factor (occurrence ratio) for occurrence [Ref. 36, p. 321, (eq. 19)].

$$C_{ij} \quad = \quad \frac{1}{1-P_j}[\phi R_{ij} - \phi P_i]$$

Assuming certain non-occurrence ($P_j = 0$), then, the probability of the ith event given that the jth event is certain to not occur is defined similarly, $S_{ij} = P_i$. A cross-impact for non-occurrence is derived [Ref. 36, p. 321, (eq. 21)].

$$C_{ij} \quad = \quad \frac{1}{P_j}[\phi P_i - \phi S_{ij}]$$

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Combining these two factors produces [Ref. 36, p. 321, (eq. 22)],

$$C_{ij} = \phi R_{ij} - \phi S_{ij}$$

Obtaining values for all the C_{ij}'s permits calculating γ_i, a term assumed to be a function of the unknown variables not specified in the event set [Ref. 36, p. 321, (eq. 23)]

$$\gamma_i = \phi P_i - \sum_{k \neq 1}^{n} C_{ik} P_k$$

By assuming the most favorable case for event i's occurrence, P_i^f, and the least favorable case, P_i^u, two γ_i's can be computed, γ_i^f and γ_i^u. This permits measuring explicitly the inaccuracy caused by ignoring higher order interactions [Ref. 37, p. 327, (eq. 45)].

$$\frac{\gamma_i^f - \gamma_i^u}{\gamma_i}$$

2. Procedure

The Turoff procedure is essentially the same as the basic approach until the point at which scenarios are generated. As in the basic approach it is necessary to: specify the event set, obtain initial probability estimates, and obtain "conditional probability" estimates. These are used to calculate the cross-impact factors as discussed

previously. If there was no change in estimate from the initial probability then $C_{ij} = 0$. With this information it is possible to calculate the remaining measures described in the preceding section.

Turoff criticized the Monte Carlo procedure as not producing a "consistent set of estimates" because the assumptions underlying it imply estimator inconsistency [Ref. 36, p. 309]. Rather than employing a random process, Turoff generates an event sequence scenario using the assumption that the events are time-independent in their occurrence.

The first step under this assumption is to select the event whose initial probability is closest to 1 or 0. If $P(i)$ is close to zero he assumes the event did not occur, if it is close to one it is assumed to have occurred. Based on this decision the probabilities for the remaining events are recalculated using the appropriate C_{ij}. This process is repeated using the events' new probabilities until all events have been decided [Ref. 36, p. 331]. This produces a "unique" scenario. Other possible scenarios are produced by changing the initial probability estimates and repeating the above procedure. This is in effect, sensitivity analysis as done in the other two approaches.

3. Analyses Performed

In presenting his approach, Turoff demonstrates only a sensitivity analysis. As in the basic approach, this is

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accomplished by adjusting one or more of the initial proba-
bilities and holding the remaining probabilities and the
cross-impact factors constant. In addition to reflecting a
conscious policy decision, this is the method whereby the
estimator determines if the behavior of the model built from
his responses is in accordance with his expectations. If
he is not satisfied, it is at this point that he goes back
and changes his initial and/or conditional estimates [Ref.
36, p. 331].

Although other types of analysis were not demon-
strated it seems most could be accomplished using this
approach. Event dominance and sensitivity could be derived
from Turoff's cross-impact matrix using a procedure similar
to Enzer's. Since Turoff's cross-impacts are presented as
a type of correlation coefficient ($\pm \infty$ in range),[23] an
indication of event desirability might be obtained through
simple summing of the positive or negative effects. Desira-
bility analysis would depend primarily on how the events
were formulated.

Turoff's matrix also includes a measure (Gamma)
of the effects of events not specified in the event set
(and higher order interactions). This can be interpreted
as an uncertainty measure. Estimator uncertainty could also

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[23]The use of correlation coefficients offers an alternate
method of interpreting respondent's meanings when they
answer the cross-impact questions. Its implications and
possible uses will be explored in Chapter Five.

be obtained by computing the range of opinion given by
a group of estimators.

4. Critique

Two major conceptual problems exist in Turoff's
technique. The first of these arises from the assumption
that estimators can be expected to provide consistent
responses. Mitchell and Tydeman reject this assumption
stating:

> [Turoff] argued that there is no need
> for usual traditional probability rel-
> ationships to hold and included a small
> example to support this assertion. In
> this example, he considered two time
> specific events and by undertaking
> usual conditional probability analysis
> concluded that $P(A|B)$ and $P(B|A)$ were
> not standard conditional probabilities.
> This is not surprising given the defin-
> tions which Turoff used; in fact, the
> finding is consistent with a time-
> dependent interpretation of conditional
> probability. The result does not support
> his claim that traditional probability
> relationships are irrelevant to cross-
> impact studies, and that violation of
> the usual probability relationships
> can be justified. The fact that
> people answer as though an ordering
> among events was implied seems to be a
> reason for explicitly recognizing this
> fact in the definition of the probability
> statement rather than ignoring it. [Ref. 29,
> p. 135].

It is difficult to conceptualize a situation in
which an individual is able to operationalize all the
relevant components of a complex problem, and quantify
their interrelationships to produce a consistent set of
probability statements defining his paradigm on demand.

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Furthermore, assuming consistency removes the formal structure provided the methodology by classical probability theory. Lacking an empirical base in the inexact sciences, it seems difficult to select an appropriate manipulation technique without some such formal theoretical basis.

The second conceptual problem arises in the scenario generation process. By assuming time-independence Turoff produced one scenario, or event outcome sequence, but there seems to be little justification for assuming that it is unique. The assumption that the most probable event in a situation would occur first, or indeed occur at all, is debatable. This would be especially true in a situation characterized by surprise. This indicates that the procedure was established arbitrarily and that several others could have been devised which would have functioned equally well (e.g., assuming the least probable event occurs and the most likely does not). Without some method of identifying and ranking all possible outcomes, production of a single scenario seems pointless.

A final criticism of this technique involves its procedure. Because respondnets had to reiterate their estimates until satisfied with the resulting coutput, an interactive computer system was required. To replicate this reiteration process for several respondents manually would require an excessive number of calculations be performed, and much time be expended in querying respondents.

The approach to be discussed in the next section seems to overcome these problems.

E. CROSS-EVENT ANALYSIS (MITCHELL AND TYDEMAN)

This approach was developed by Mitchell and Tydeman and presented in 1978 as a variation to Duperrin and Godet's SMIC-74, which is discussed in the following section. As has been shown, Mitchell and Tydeman felt it was inappropriate to ignore time dependence when obtaining estimates. They felt that respondents normally interpret the questions posed for eliciting the conditional probabilities in a time-dependent manner. Mitchell and Tydeman attempted to use these time-dependent estimates to derive classical conditional probabilities [Ref. 39].

Mitchell and Tydeman also recognized that the elicited information could be inconsistent in terms of classical probability relationships. To minimize this problem they used average group responses which reduced the instances of pairwise inconsistency. In order to correct inconsistencies which did manifest themselves, they developed two fitting procedures, least squares and minimum standard deviations. These procedures will be reviewed below, the authors also suggested that Enzer's boundary rule could be used to resolve inconsistencies [Ref. 23, p. 18].

1. Assumptions

The major difference between this and the other approaches is that it uses causal time-dependent subjective

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probability estimates to identify first order interrela-
tionships among selected events, defining them as classi-
cal probability relations. This approach uses a specific
time horizon, rather than treating time as a random variable.

Subjective estimates were obtained which completely
identified the eight possible ordered outcomes permitted
by any event pair. These outcomes can be identified explicitly
for any event pair (i,j), and each has an associated unique
probability (P_1 through P_8). These are [Ref. 29, p. 139]:

$$
\begin{array}{llll}
(i,j) &
\begin{cases}
i \begin{cases} i \\ \bar{j} \end{cases} \\
\bar{i} \begin{cases} j \\ \bar{j} \end{cases} \\
j \begin{cases} i \\ \bar{i} \end{cases} \\
\bar{j} \begin{cases} i \\ \bar{i} \end{cases}
\end{cases}
&
\begin{array}{l}
i\,j \longrightarrow P_1 \\
i\,\bar{j} \longrightarrow P_2 \\
\bar{i}\,j \longrightarrow P_3 \\
\bar{i}\,\bar{j} \longrightarrow P_4 \\
j\,i \longrightarrow P_5 \\
j\,\bar{i} \longrightarrow P_6 \\
\bar{j}\,i \longrightarrow P_7 \\
\bar{j}\,\bar{i} \longrightarrow P_8
\end{array}
\end{array}
$$
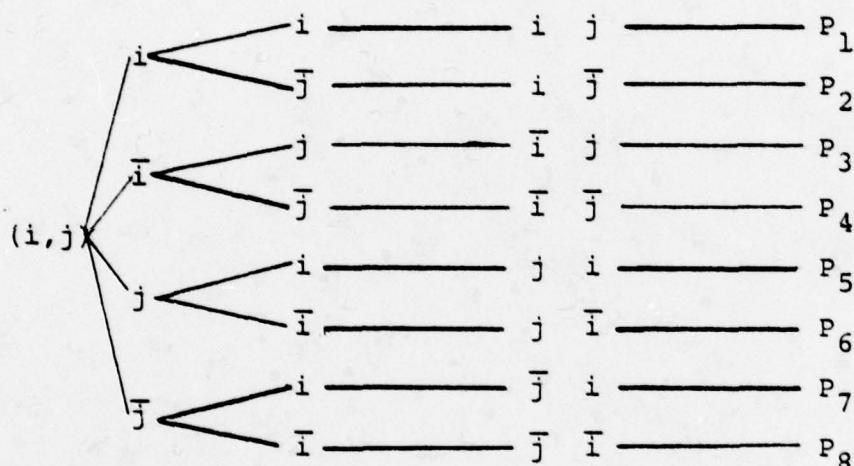
Since these outcomes are exhaustive and mutually
exclusive, certain conditions must apply [Ref. 39, p. 138]:

$$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 = 1 \qquad \text{eq. 1}$$

$$P_1 + P_2 \qquad\quad + P_5 \quad + P_7 = P(i) \qquad \text{eq. 2}$$

$$P_1 \qquad + P_3 \quad + P_5 + P_6 \qquad\quad = P(j) \qquad \text{eq. 3}$$

The authors feel that respondents can be expected to supply four time-dependent conditional probabilities [Ref. 39, p. 139].[24]

$$P(i|j_{first}) = C_1 = P_5 \div (P_5 + P_6) \qquad \text{eq. 4}$$

$$P(j|i_{first}) = C_2 = P_1 \div (P_1 + P_2) \qquad \text{eq. 5}$$

$$P(i|\overline{j}_{first}) = C_3 = P_7 \div (P_7 + P_8) \qquad \text{eq. 6}$$

$$P(j|\overline{i}_{first}) = C_4 = P_3 \div (P_3 + P_4) \qquad \text{eq. 7}$$

A fifth time-dependent relationship was also presented for estimation [Ref. 29, p. 139].

$$P(i_{first}|i \text{ and } j \text{ occur}) = C_5 = P_1 - (P_1 + P_5) \qquad \text{eq. 8}$$

Solving these eight relationships as simultaneous equations, the developers demonstrate that the probabilities for an event pair's ordered outcomes can be calculated from the information provided by the respondents' estimates [Ref. 29, p. 140].

$$P_1 = \frac{(C_3 C_4) - (C_3 P_i) - (C_4 P_i)}{\gamma - \alpha C_4 - \beta C_3} \qquad P_2 = \left[\frac{(1 - C_2)}{C_2}\right] P_1$$

---

[24] If these last two equations are too difficult to estimate, the developers derive a method whereby they can be computed [Ref. 29, p. 141].

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$$P_3 = P_j - \frac{\beta P_1}{C_5} \qquad\qquad P_4 = \left[\frac{(1 - C_4)}{C_4}\right] P_3$$

$$P_5 = \left[\frac{(1 - C_5)}{C_5}\right] P_1 \qquad\qquad P_6 = \left[\frac{(1 - C_1)}{C_1}\right] P_5$$

$$P_7 = P_i - \left[\frac{(\alpha P_5)}{C_5}\right] \qquad\qquad P_8 = \left[\frac{(1 - C_3)}{C_3}\right] P_7$$

where:

$$\alpha = (1 - C_5) + \frac{C_5}{C_2} \;\; ;$$

$$\beta = [(1 - C_5) - C_1] + C_5 \;\text{, and}$$

$$\gamma = \frac{(C_5 C_1) + C_2 - (C_5 C_2)}{(C_2 C_1)}$$

Using these relationships Mitchell and Tydeman calculate the classical conditional probabilities for each event pair [Ref. 29, p. 140].

$$P(i|j) = (P_1 + P_5)/(P_1 + P_2 + P_5 + P_7)$$

$$P(j|i) = (P_1 + P_5)/(P_1 + P_3 + P_5 + P_6)$$

As mentioned earlier, the developers derived a method to calculate non-occurrence if it could not be estimated. To calculate the conditional probabilities without estimating non-occurrence Mitchell and Tydeman adopt the following procedure. To obtain conditional probabilities one of the relationships needed is:

$$P(i \text{ and } j) = P_1 + P_5$$

or

$$P(i \text{ and } j) = P(i \text{ and } j \text{ first}) + P(j \text{ and } i \text{ first})$$

$$= P(i|j_{first}) \, P(j_{first}) + P(j|i_{first}) \, P(i_{first})$$

This can be obtained by estimating: $P(i_{first})$ and $P(j_{first})$ or this can be approximated by:

$$P(i_f) = P(i_f|i \quad j) \, P(i) \quad \text{and similarly for } P(j_f)$$

substuting:

$$P(i \text{ and } j) \doteq C_5 C_2 P(i) + (1 - C_5) C_1 P(j)$$

which is:

$$P(i \text{ and } j) \doteq P_1 + P_5 + E$$

where the error E is small for independent events, and more significant for highly correlated events (10-20%) [Ref. 29, p. 141].

$$E = (P_1/P_1 + P_2)[(P_1 P_7 - P_2 P_5)/(P_1 + P_5)] + (P_5/P_5 + P_6)\frac{(P_3 P_5 - P_1 P_6)}{(P_1 + P_5)}$$

Inconsistency is manifested when a negative value is calculated for any of the probabilities P_1 through P_8. Standard fitting procedures may be used to resolve inconsistencies by hypothesizing that there exists a "true" or consistent value (*) for each respondent's estimate. This value is determined to be one which is "as close as possible" to the respondent's estimates and makes all $P_1, \ldots, P_8 \geq 0$. The developers present two procedures which utilize this hypothesis: least squares, and minimum standard deviations [Ref. 29, p. 142].

The least squares procedure produces a minimization program "with a quadratic objective function and non-linear constraints" [Ref. 29, p. 142]. This program would not be easy to solve by hand. Minimizing the absolute standard deviations produces a moderately sized linear program with linear constraints [Ref. 29, p. 143-4]. In addition this program could be expanded to provide for overall consistency by including scenario probabilities and terms for higher order interactions [Ref. 29, p. 145]. If this correction procedure proves too lengthy, the authors suggest Enzer's boundary rule could be used to resolve pairwise inconsistencies.

2. Procedure

To obtain the events for analysis the authors used a procedure they termed "event assessment". For each candidate event, the respondents provide not only the

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likelihood that the event occurs within a specified time horizon, but an estimate of its significance given that it occurs. An event impact score is then calculated as a weighted function of the product of probability and significance. In this way an analysis event set can be selected from the events having the highest impact scores, probabilities, or significance ratings [Ref. 23, p. 8].

The next step is to determine the events' time-dependent conditional probabilities by eliciting responses for questions structured to provide values for equations four through eight. These responses are aggregated and used to compute the ordered outcome probabilities P_1 through P_8, which are used to compute the classical conditional probabilities. If any inconsistencies appear in this phase (any P_1 through $P_8 < 0$), they are eliminated using the boundary rule or fitting technique.

The next step is to generate scenarios, or event sequence outcomes. For this procedure Mitchell and Tydeman used a variation of the Duperrin and Godet technique. This technique assumes that for an n nevent system there are $r = 2^n$ states (scenarios). Each state "E_k" has a unique probability π_k [Ref. 48, p. 305].

An event's theoretical probability P*(i) is defined as its frequency of occurrence in all the possible states [Ref. 49, p. 64].

$$P*(i) = \sum_{k=1}^{r} \theta_{ik} \pi_k \qquad \text{for all } i$$

where

$$\theta_{ik} = \begin{cases} 1 & \text{if event } i \text{ forms part of } E_k \\ 0 & \text{otherwise} \end{cases}$$

A similar definition can be applied to the theoretical conditional probabilities $P*(i|j)$ [Ref. 49, p. 64].

$$P*(i|j) = \sum_{k=1}^{r} t(ijk) \pi_k / P*(j) \qquad \text{for all } i,j$$

where

$$t(ijk) = \begin{cases} 1 & \text{when events } i \text{ and } j \text{ form part of } E_k \\ 0 & \text{otherwise} \end{cases}$$

and

$$P*(i|\overline{j}) = \sum_{k=1}^{r} s(ijk) \pi_k / 1 - P*(j) \qquad \text{for all } i,j$$

where

$$s(ijk) = \begin{cases} 1 & \text{when events } i \text{ and } \overline{j} \text{ form part of } E_k \\ 0 & \text{otherwise} \end{cases}$$

Recognizing standard probability constraints [Ref. 49, p. 65]:

$$0 \le P^*(i) \le 1$$

$$P^*(i|j) = P^*(j|i)P^*(i) = P^*(ij)$$

$$P^*(i|j)P^*(j) + P^*(i|\overline{j})P^*(\overline{j}) = P^*(i)$$

produces:

$$\sum_{k=1}^{r} t(ijk)\pi_k = P^*(ij) = P^*(ji)$$

and

$$P^*(i|\overline{j})P^*(\overline{j}) = \sum_{k=1}^{r} s(ijk)\pi_k = P^*(i) - P^*(ij)$$

Therefore, given a consistent probability set, any set of π_k values which satisfy:

$$P^*(i) = \sum_{k=1}^{r} \theta_{ik}\pi_k \quad \text{for } i = 1,2,\ldots,n$$

$$P^*(ij) = \sum_{k=1}^{r} t(ijk) \quad \text{for } i = 1,2,\ldots,n-1; \ i < j \le n$$

and

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$$\sum_{k=1}^{r} \pi_k = 1 \qquad \pi_k \geq 0 \qquad \text{for all } k$$

are possible solutions to the scenario probabilities [Ref. 49, p. 65].

Instead of the Duperrin and Godet quadratic objective function, Mitchell and Tydeman solve a linear equation in terms of consistent probabilities to obtain a unique solution. This program is [Ref. 49, p. 65-6]:

$$\text{minimize } Z = \sum_{ij}^{n} [P(i|j)P(j) - P*(ij)]^2 + \sum_{ij}^{n} [P(i|\bar{j})P(\bar{j}) - P*(i) + P*(ij)]^2$$

$$\text{subject to:} \quad \sum_{i=1}^{n} P*(i) - \sum_{i-1}^{n} \sum_{j=i+1}^{n} P*(ij) \leq 1$$

$$P*(ij) \geq 0 \quad \text{all } j > i$$

$$P*(i) \leq 1 \quad \text{all } i$$

$$\left. \begin{array}{l} P*(i) \geq P*(ij) \\[2mm] P*(j) \geq P*(ij) \end{array} \right\} \quad \text{all } j > i$$

3. Analyses Performed

The cross-event approach uses a different method to determine event dominance and sensitivity. An event's dominance may be estimated by summing, for all other events,

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the absolute deviation of the conditional probability, given that the event occurred first, minus the event's original probability. This value can be standardized, or an "elasticity" measure adopted to reflect event likelihood. An event's sensitivity can be computed in a similar fashion [Ref. 23, p. 12].

Although it was not demonstrated, causal relationships could be traced as in the other approaches by filling in the cross-event matrix. This would be useful in an analysis Mitchell and Tydeman term "system impact analysis" which evaluates the possible event sequence scenarios' worth.

System impact analysis used additional subjective ratings concerning an event sequence scenario's expected impact (magnitude and direction) on specified system components and the "expected consequences for system outcomes (performance measures)" (i.e., desirability) [Ref. 23, p. 14]. In this manner a different set of possible response actions may be identified for each scenario.

The final analysis they suggest is "strategy evaluation". This procedure relates a set of feasible potential strategies (response actions as determined using system impact analysis) to each event sequence scenario (the most probable ones), and uses a set of objective criteria (obtained from the decision-makers) to evaluate the strategies for each possible situation [Ref. 23, p. 15].

4. Critique

A major advantage in this approach is that it eliminates the difficulty in interpreting estimator responses. Estimators are asked for time-dependent relationships which are then used to calculate classical conditional probabilities. Furthermore, if non-occurrence is too difficult for respondents to conceptualize, it can be calculated, introducing a small error.

The capability to compute the conditional probabilities results in the further advantage of providing a logical background for the analysis. Classical probability relationships, it is suggested, can be used to insure consistency and resolve inconsistencies without requiring respondents to re-estimate. In addition, the procedure develops a method for calculating and ranking event sequence outcome probabilities.

With the scenario ranking, introducing subjective estimates concerning system impact and objective measures for comparison extends the types of decision-aiding analysis which can be performed. With the Mitchell and Tydeman method it is apparently possible to address questions relating to the event sequence scenarios' desirability and strategy effectiveness. However, in system impact analysis:

> Problems still face the analyst, for
> example, eliciting an exhaustive objective
> set, ensuring mutual independence of
> objectives, devising procedures for
> measuring outcomes, determining consis-
> tent weightings for the objectives

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and specifying procedures for aggregation.   [Ref. 23, p. 15].

These problems seem even more complex for decisions involving national objectives and foreign policy options.

A final difficulty lies not in the conceptual realm, but in the method's implementation. Generating the scenario probabilities with the linear equation for a large event set would be very difficult without access to a computer. In order to replicate this process manually it appears necessary to severely limit the event set to be analyzed.

F.   OTHER APPROACHES

Besides the approaches to cross-impact analysis discussed so far, several additional techniques have been proposed. These techniques were concerned primarily with assessing the relative rankings among the event sequence scenarios. They also introduced alternative methods to insure estimate consistency, and to resolve inconsistencies.

These techniques took significantly different approaches towards resolving these problems than the techniques just reviewed. However, each approach requires a computer package. Thus they were evaluated as being inappropriate for demonstration and analysis in the present project. It was felt to be impractical to replicate their procedures for confirming consistency, establishing probability bounds and revising estimates using manual methods. However, these approaches have merit in presenting promising alternatives

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to cross-impact analysis and will be discussed briefly.
This discussion is offered in the interest of complete-
ness, and to justify the conclusion to omit them from
evaluation.

   1. SMIC-74 (Duperrin and Godet)

        Duperrin and Godet felt that cross-impact analysis
could be used to construct and rank event sequence scenarios.
In recognition of the fact that the estimators could be
inconsistent in stating probabilities, they attempted to
derive "theoretical" scenario probabilities which were
implied by the estimator responses. Using those implied
probabilities they attempted to revise the estimated
responses to fit the theoretical scenario probabilities
and produce a consistent set of estimate. The following
diagram summarizes their procedure [Ref. 48, p. 306].

                          Figure 2

                    THE SMIC-74 PROCESS

Raw individual & conditional probabilities	System probabilities or scenarios	Finished individual & conditional probabilities
Inconsistent Incomplete expert opinion	Conversion	Complete & consistent information
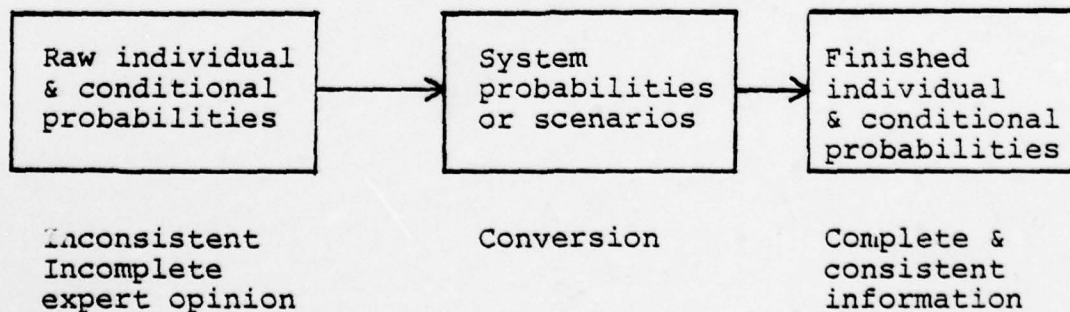
        In order to accomplish this process Duperrin and
Godet developed a minimization program to minimize the

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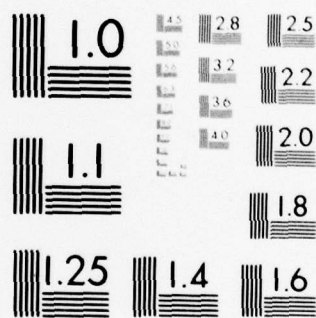
MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

difference between the estimated factors $P(i|j)$ resulting
from the experts' responses and the theoretical factors,
$P*(i|j)$ and $P*(i)$, expressed in terms of even sequence scenario
probabilities, π_k, [Ref. 48, p. 306]. The rationale behind
this approach was covered in the Mitchell and Tydeman re-
view. The Duperrin and Godet procedure utilized a minimi-
zation program of quadratic form with linear constraints
[Ref. 48, p. 306-7].

$$\text{minimize } Z = \sum_{ij}^{n} [P(i|j)P(j) - \sum_{k=1}^{r} t(ijk)\pi_k]^2$$

$$+ \sum_{ij}^{n} [P(i|\bar{j})P(j) - \sum_{k=1}^{r} s(ijk)\pi_k]^2$$

$$\text{subject to } \sum_{k=1}^{r} \pi_k = 1, \ \pi_k \geq 0, \text{ for all } k$$

Obviously, solving this program would involve utilizing
a large computer package.

Furthermore, according to Mitchell and Tydeman the
ranking produced is not unique "in that the quadratic
programme has other possible solutions", and the "number of
probability sets which satisfy the quadratic is potentially
very large" [Ref. 49, p. 64]. These conclusions led Mitchell
and Tydeman to propose their approach discussed previously.

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2. Sequential Approach (Sarin)

Sarin's approach is concerned primarily with event sequence scenario generation. Sarin derived a larget set of classical probability constraints which information elicited on initial and conditional probabilities must satisfy in order to be consistent (e.g., for a set of six events there are sixty-four conditions the initial probabilities alone must satisfy to be consistent.) [Ref. 38, p. 54-5]. He then develops a set of linear equations with which to compute the 2^n possible event sequence outcome probabilities and satisfy the constraints [Ref. 38, p. 59-60].

Sarin proposes that an interactive computer program be used in conducting the analysis. The program checks the estimator inputs for consistency, computes and supplies bounds for further estimates, and uses the consistent inputs to solve the linear equations producing the scenario probabilities [Ref. 38, p. 58]. This approach solves the consistency problem through providing respondents with immediate feedback.

In this approach, it is possible to consider higher-order interactions with the computer's aid. Because these interactions are often so tightly bound it becomes unnecessary to estimate them [Ref. 38, p. 59]. Sarin also concludes that each discrete event influences only two scenarios, or event outcome sequences, and it is therefore possible to conduct sensitivity analysis through considering, and changing initial values for, only the events which influence the top

ranked scenarios. In this manner it is possible to estab-
lish bounds on P(i) under which the scenario ranking does
not change [Ref. 38, p. 60]. Similar bounds can be computed
for the conditional probabilities, each of which influence
only four scenarios.

Once again, the need for an interactive computer
program makes demonstrating this approach infeasible in the
current study. Furthermore, no mention is made of conducting
the other types of analysis (event dominance, sensitivity,
and tracing causal effects) which would be necessary in a
problem considering short term effects. Although such
analyses could undoubtedly be accomplished, it would require
making major modifications to the program.

3. KISM (Kane)

In 1972, Kane advanced a cross-impact procedure
which dealt with developing trends rather than discrete
events. His trend variables behaved in a logistic fashion
(as Gordon proposed). In this formulation the net effects
of the cross-impact coefficients went to zero as the trends
reached their maximum or minimum values [Ref. 47, p. 132].
If these values are restricted to a range between one and
zero, the impact of one trend on another is given by
[Ref. 47, p. 133]:

$$x_i(t + \Delta t) = x_i(t)^{P_i}$$

where

$$P_i(t) = \frac{1 + \frac{\Delta t}{2} \sum_{j=1}^{n} (|\alpha_{ij}| - \alpha_{ij}) \, x_j}{1 + \frac{\Delta t}{2} \sum_{j=1}^{n} (|\alpha_{ij}| + \alpha_{ij}) \, x_j}$$

or

$$P_i(t) = \frac{1 + \Delta t \, |\text{sum of negative impacts on } x_i|}{1 + \Delta t \, |\text{sum of positive impacts on } x_i|}$$

where

t = time

α_{ij} = the cross-impact value

x_i = trend i

x_j = trend j

The relationship was modelled on a computer using the differential [Ref. 49, p. 133].

$$\frac{dx_i}{dt} = - \sum_{j=1}^{n} a_{ij} x_i x_j \ln x_i$$

These developments can be modelled for any time increment and analyzed by varying the initial assumptions regarding the probabilities of the trends and the cross-impacts. Initial

trend and cross-impact values were obtained as in the

standard approaches [Ref. 47, p. 131].[25]

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[25]This approach's intuitive appeal is apparent from the
computer output generated, which shows the interactions as
they develop over time. A sample output for a transportation
study is presented below along with the cross-impact matrix
from which it was derived. The values in the matrix are a
series of +'s and -'s which were converted directly to integer
values. Another interesting point is that a trend can impact
itself in this approach. Initial probabilities for the
trends as established by the developer were [Ref. 47, p. 137]:

```
        Auto Use = .8
        Comfort  = .6
    and Convenience
        Freedom  = .6
        Speed    = .5
        Auto Cost= .2
```

Table 2

An Interaction Matrix Describing

the Present Pattern of Public Private Transportation

impact	ST	AUTO USE	C & C	FREEDOM	SPEED	OUTSIDE WORLD
COST	0	--	++	`	+	-
USE	++	+	++	++	+-	+
C & C	+	--	0	0	0	+
	+	---	0	0	0	++
SPEED	+	---	0	+	0	++

Fig. Projected trends

as set by the impact matrix given in Table 2.

AUTO USE

FREEDOM

C & C

SPEED

COST

time
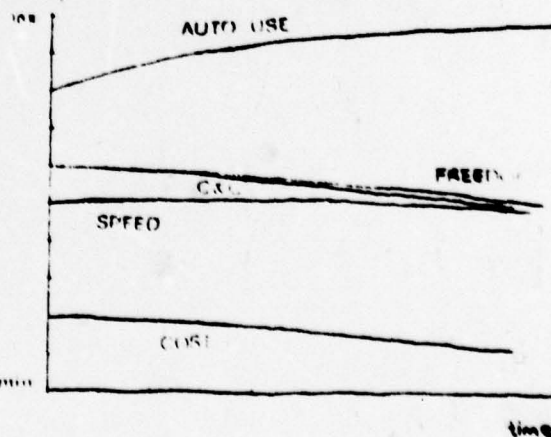
Lipinski and Tydeman have attempted recently to extend KISM to include a consideration of discrete events, non-constant trends, and their interactions [Ref. 50]. As with the other approaches discussed in this section this method suffers from the requirement that a large computer package be available for demonstration.

G. MAJOR APPROACH EVALUATION

Four primary approaches to cross-impact analysis have been identified and explained.

The Basic Method -- Attempted to elicit quantitative values for interactions among events and revised the initial probability estimates through a quadratic manipulation. The cross-impact concept used was incompletely defined, and subject to several inter- pretations.

Enzer's Modification -- Obtained estimates in terms of likelihood ratios, included non-occurrence, addressed pairwise consistency, and revised the conditional probability estimates.

The Turoff Approach -- Assumed estimator consistency, used inputs to derive correlation coefficients, and attempted to identify a unique scenario.

Cross-Event Analysis -- Derived conditional probability relationships from causal time-dependent estimates and used a linear program to identify and rank scenarios.

Although the major problems associated with each of these approaches were identified in the discussion, selecting an approach for application cannot be made unless the approaches are systematically compared. The evaluation criteria developed in Chapter Two will be used for this purpose. Those criteria were:

1. Is the event scope adequate?

2. Can events be rated on importance/desirability?

3. What types of analysis are permitted?

4. Is the approach computer adaptable?

5. Are required estimates clearly formulated?

6. Are estimates consistent, or can consistency
    be obtained?

7. What manipulation algorithm is used?

8. Is the procedure logical/justifiable?

9. How is consistency obtained?

10. How are scenarios generated, can they be ranked?

11. How many estimates are required?

12. What types of computations must be performed?

13. How many terms are involved?

14. How many calculations are required?

1. Evaluation

The following table summarizes the findings discussed
in the preceding sections in relation to these evaluation
criteria. The four primary cross-impact approaches identi-
fied form the column headings. Each entry in the table repre-
sents a brief summary of how an approach was evaluated as to
meeting the numbered criteria which form the row headings.
Specific conclusions based on this evaluation will be pre-
sented in the selection section of this chapter which follows
Table One.

A few of the criteria were omitted from the table
because they were met equally well by all approaches. These

TABLE ONE

APPROACH EVALUATION

CRITERION	BASIC METHOD (GORDON)	MODIFIED METHOD (ENZER)	ALTERNATIVE METHOD (TUROFF)	CROSS-EVENT (MITCHELL AND TYDEMAN)
3.	a. Event dominance & sensitivity b. Sensitivity analysis c. Attempted to trace causal linkages. d. Identified possible scenario (1)	a. Event dominance and sensitivity b. Trace causal effect more explicitly c. Estimated uncertainty. d. Sensitivity analysis e. Evaluated desirability of scenarios.	a. Uncertainty measure for higher order effects and un-specified events. b. Sensitivity analysis. Generates possible c. Generates possible scenario (1).	a. Event assessment System Impact Analysis (response options) b. System Impact Analysis (response options) c. Scenario evaluation (ranking and desirability)
5.	Cross-impacts not defined precisely, ignored non-occurrence	Possible confusion when relating estimates to conditional probability	Assumes consistency, defines estimates as conditional probability computes correlation coefficients.	Causal time-dependent relationships elicited
6.	Not addressed	Attempts to assure pairwise consistency using classical probability.	Assumed	Uses causal time-dependent estimates to derive classical conditional probabilities
7.	Quadratic	Estimated factor (algebraic)	Computed factor (algebraic)	Computed factor (algebraic)
8.	Several problems.	Some basis. Combining causal estimates with classical probability a problem	Assumes consistency which is debatable.	By completely enumerating event pair outcomes derives conditional probabilities.

TABLE ONE (CONT.)

CRITERIA	BASIC METHOD	MODIFIED METHOD	ALTERNATIVE	CROSS-EVENT
9.	No	Apply boundary rule (assumed estimator intent correct)	No	Fitting procedures
10.	By final probability rank. (not unique)	Monte Carlo procedure. (no rank)	Assumed time-independence. (not unique)	Linear program (probability ranking)
11.	a. P_i's = n b. date = n c. $P(i\|j)$'s = $2(n^2-n)$ (mode and strength) Total = $2n^2$	a. P_i's = n b. rating = n^2 c. $P(i\|j) = (n^2-n)$ d. $P(i\|\bar{j}) = (n^2-n)$ (optional) e. P_i's desirability = n Total = n^2+2n (option = $2n^2+n$)	a. P_i's = n b. Cond. = n^2-n c. Gamma = 2n Total = n^2+2n	a. P_i's = 2n b. $C_{1-4} = n^2-n$ c. $C_5 = \dfrac{n^2-n}{2}$ Total = $n^2+n+\left(\dfrac{n^2-n}{2}\right)$
12.	a. Quadratic	a. Likelihood ratio (Occ. and non-occ.) b. Bayesian probability (non-occurrence and consistency)	a. C_{ij}'s b. Y_i c. effect of higher order interactions	a. P_{1-8} b. Conditionals c. Linear program
13.	a. 3	a. 2 b. 4	a. 3 b. n c. 3	a. various b. 4 c. 6
14.	a. n(n-1)	a. each event pair b. optional for each event (plus any inconsistencies)	a. for each event pair (n) b. each event (n) c. each event (n)	a. each event pair $(8 x_{ij})$ b. each event (2n) c. once

general criteria will be commented on below. In considering
the last three criteria which addressed the required compu-
tations' form and number (criteria 12, 13, and 14), two
assumptions were made: (1) The types of computations and
number of terms (criteria 12 and 13) include all possible
computations which could be necessary (including computing
cross-impacts and resolving inconsistencies) in demonstrating
the approach, except for those involved in aggregating esti-
mates to produce an average value. These computations
would not be approach dependent. (2) The number of computa-
tions (criterion 14) does not include computations required
in either aggregation nor resolving inconsistencies, as the
latter depends on the knowledge of the respondents.

The general criteria were found to be:

a. Event Scope (1)

Event formulation in all the methods can cover
any subject or combination of subjects. The only restric-
tions concern the linkages between events, and the way in
which events are stated. These restrictions apply equally
to all approaches.

b. Event Rating (2)

Although each approach did not rate events for
selection for analysis, the procedures proposed by Enzer and
by Mitchell and Tydeman are flexible enough to be applied in
any cross-impact analysis. Thus once a technique is selected
it is necessary only to select a method to evelute the events,

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and explain the criteria for subjective estimates to the respondents.

c. Computer Adaptability (4)

Each method reviewed acknowledged that a computer would be necessary in order to deal with a large event set. Turoff's approach required that an interactive computer be available to query respondents, and present them with the results produced by their estimates. Enzer proposed that a computer be used to provide probability bounds based on estimator responses for each event pair. It appears that all necessary calculations could be easily programmed, and that a software package could be developed to elicit responses for any type of event. Therefore, it is felt that all the approaches may be considered computer adaptable.

The evaluation of each approach in relation to the remaining criteria is presented in Table One. This evaluation highlights the major differences between each approach.

2. Selection

As the discussion below indicates, of the four major cross-impact approaches evaluated, the Turoff method seems to be the least promising for demonstration in this study. The basic (Gordon) method was developmental and substantially extended by Enzer. Enzer's approach, however, involved difficulties in relating respondents' estimtes (which could be interpreted as providing causal time-dependent probabilities)

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with classical probability theory. This shortcoming would make it difficult to explain the technique to respondents. In contrast, the Mitchell and Tydeman approach develops procedures to calculate classical conditional probabilities from the apparently time-dependent estimates, and provides a scenario ranking algorithm. For these reasons it was selected for demonstration in this study. The following discussion will present the rationale behind these conclusions, and indicate anticipated problems in implementing the selected approach.

Due to its assumption that estimators are consistent, the Turoff approach requires that they be allowed to revise their estimates until satisfied with the model produced. This requirement, as mentioned previously, would be hard to meet in a manual demonstration. The assumption of consistency cannot be validated because the cross-impacts are calculated in terms of correlation coefficients (ranging, however, from $+\infty$ to $-\infty$), which do not reveal inherent inconsistencies as do probabilities when they exceed unity or become negative.

The Turoff approach is further limited by its time-independence assumption for scenario generation. This produces only one scenario for each set of estimates, and there is no reasonable basis for assuming that it is either a unique or most probable scenario. Finally, the time-independence assumption would be unworkable in an analysis

attempting to examine the effects produced by discrete
response options which might be implemented in reacting to
a developing crisis situation. The rationale and structure
of this type of analysis will be developed more fully in the
extension section of this chapter which follows.

The basic cross-impact approach, developed by Gordon
and Hayward, while important in introducing the technique's
basic concepts and potential applications was primarily a
developmental approach. As such it suffered from several
conceptual shortcomings which were eliminated in later
approaches. These shortcomings were reviewed extensively
elsewhere in this study, and stem from the use of the quadratic
manipulation technique, ignoring non-occurrence, and incom-
plete explanation of the cross-impact factors. Because this
approach was greatly modified by Enzer it was decided to
eliminate it from further consideration for selection.

Enzer's modified approach dealt with many of the
problems inherent in the basic method. He developed an
uncertainty measure, addressed non-occurrence and consistency,
and eliminated the quadratic manipulation. However, in
developing these improvements he failed to solve the problem
of how to interpret estimator responses. Enzer recognized
that causal relationships were being elicited, but used
classical probability relationships to compute non-occurrence
and resolve inconsistencies. The cross-impacts were defined
as likelihood ratios denoting an event's change in probability
given the occurrence of another event. This change was

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denoted by the conditional probability relationship $P(i|j)$, however, the actual relationship seems to involve time-dependence. Therefore, this approach seems to be limited by the incomplete incorporation of two types of probabilistic relationships. In order to demonstrate a technique it will be necessary to explain its rationale to the selected study group. This requirement makes the modified approach unsuitable for demonstration because of the difficulty in explaining these fine distinctions and their implications to respondents unaccustomed to providing this type of information.

Cross-event analysis assumes that respondents normally think in terms of time-dependent probabilities, and uses these estimates to calculate the conditional probabilities from the relationships implied by the estimator's responses. Because this approach seeks to explicitly identify quantitative values for all possible outcomes of each event pair, a greater number of subjective estimates is required. However, the questions used to obtain these estimates are formulated in a manner which appears to be more closely akin to suspected individual thought processes $(P(i|j_{first}))$.

Since these estimates are used to compute the probabilities of the eight possible ordered outcomes and then to calculate the classical conditional probabilities, more computational steps are involved in using this procedure. These formulae are relatively basic and can be easily programmed on a hand-held calculator. This extra burden is, therefore, not considered excessive in light of the advantages gained.

Using the time-dependent causal estimates, pairwise probabilistic consistency is automatically checked when computing the probabilities of the ordered outcomes. By specifying values for these outcomes it is possible to derive a logical transition to the classical conditional probabilities. This avoids the problem of applying Bayesian probability relationships to causal estimates, and eliminates the need to adopt less supportable assumptions - such as estimator consistency. At the same time, because it is possible to use the classical probability relationships, the Mitchell-Tydeman method is given a firm methodological footing.

Finally, Mitchell and Tydeman's cross-event approach provides an algorithm for computing scenario probabilities. This capability is necessary if decision-makers are to be provided a means of assessing possible courses of action in responding to ongoing developments. Scenario probabilities cannot be obtained under the Turoff method's assumption of time-independence, and could only be derived from the Enzer method by conducting an excessive number of Monte Carlo runs (exceeding the number of possible event sequences).

For these reasons, the Mitchell and Tydeman cross-event analysis method was selected for demonstration and evaluation in this study. Because the purpose of the demonstration is to evaluate cross-impact analysis' potential as a decision aid in crisis situations, several modifications to the approach were considered necessary. These modifications, presented below, were intended to extend the method

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in order to evaluate policy options for response in a
developing situation.

H. EXTENSION

This section will discuss several methodological
alterations through which cross-event analysis can be
extended as a decision-aid for use in crisis situations.
Four aspects of the methodology will be dealt with. These
are: (1) the time span of analysis, (2) identifying policy
options for inclusion in the event set, (3) the method of
analysis, and (4) scenario generation.

1. Time Span

Crisis situations normally occur without adequate
warning and allow a short time for response. As Enzer and
Alter pointed out, the time span usually considered in a
cross-impact analysis is determined by the amount of time
required for an event's impact to be felt by another event
[Ref. 40, p. 233]. Since the technique being explored here
is intended to evaluate response options, it is felt that
this time span should be kept relatively short.

In a crisis situation, it seems reasonable to assume
that most response options would be designed to have an
immediate effect in altering the situation in some desired
direction. For this reason, it appears desirable to limit
the analysis to a consideration of the two weeks or so follow-
ing the identification of a crisis. As there is almost no
time lag involved, the event prediction need only involve

occurrence and non-occurrence, rather than exact dates. This
is a level one analysis described in Johnson [Ref. 40],
which predicts only those events which occur by a specific
date. In providing initial estimates, respondents will not
be asked for occurrence dates, in providing causal time-
dependent estimates any event may be considered to occur
before any other.

In the analysis, the sequence in which events occur
will be revealed through scenario generation. As will be
shown below, this will aid in evaluating likely scenarios for
plausability. This assumption would not be valid if the
effects of policy options were to be examined in their full
context. As has been noted, careful evaluation would require
an assessment of a response option's long-term effect, not
only on the crisis situation. In a "real world" application
the short-term and long-term analyses could be conducted
simultaneously to identify a possible response to control the
crisis and to evaluate its potential future effects. Such
an approach was not adopted here because of this study's
developmental and exploratory character.

2. Identifying Policy Options

The normal procedure in cross-impact analysis has
been to evaluate the effects produced by implementing policy
options through arbitrarily increasing or decreasing selected
events' initial probabilities. This seems to be contrary to
a basic goal of the approach, which is to identify an event's
unanticipated effects. Furthermore, Gordon and Hayward

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hypothesized that an event normally has a predecessor or precedes another event [Ref. 26]. It was the purpose of the technique to systematically assess these interactions. In the normal sensitivity analysis, a policy option is excluded from the matrix, and assumed to have only the effect intended.

In the Mitchell and Tydeman approach, subjective assessments are made of the impact that specific strategies have on the various scenarios. This requires a prior "System Impact Analysis" to assess how the occurrence of a scenario impacts identifiable system attributes, and the development of "objective criteria" to evaluate policy strategies. It has been pointed out that the validity of this process would be tenuous for problems involving national objectives. Furthermore, it increases the number and complexity of the subjective estimates required.

In an effort to simplify the process of assessing the impact of policy options on situational outcomes, this study will attempt to identify specific policy responses available for dealing with the hypothetical situation and include them in the original cross-event matrix. These response options will be identified and assessed as any other event which might develop from the given situation under normal circumstances. Using this approach will eliminate the need for "System Impact Analysis". Normal sensitivity analysis will still be conducted to determine response option flexibility in the event that available information was misleading and/or the problem components were evaluated incorrectly

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by the respondents. Including response options in the event
set also permits other extensions.

3. Method of Analysis

One possible extension involves the type of analysis
performed by evaluating the causal relationships contained
in the cross-event matrix. If the events representing policy
options are separated from the events representing situation
developments a four-quadrant matrix is formed as represented
below.

FIGURE THREE

FOUR-QUADRANT CROSS-EVENT MATRIX

the effect on
this event is ——————→

		D_1	D_2	D_3	O_1	O_2	O_3
if this event occurs	D_1	I.			II.		
	D_2						
	D_3	$P(D\|D)$			$P(O\|D)$		
where:	O_1	III.			IV.		
D = situation development	O_2						
ment	O_3	$P(D\|O)$			$P(O\|O)$		

where:
  D = situation
      develop-
      ment
  O = policy
      option

(note: the diagonal cells can still contain the initial
        probabilities)

Because the subjective estimates used to obtain the
conditional probabilities are in a causal time-dependent
form, the following interpretations might be given to each
of the four quadrants.

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I. (D|D) -- Represents the situation as it might develop assuming no corrective action is taken. This depicts the results of allowing a given crisis to continue.

II. (O|D) -- Represents how the occurrence of given developments effect the probabilities of various response options. The occurrence of certain developments may make a response option more attractive. (It is felt that at this point not enough information is available to use this interaction to predict which response option may be selected, only whether or not the respondents consider it more attractive.)

III. (D|O) -- Represents the effect on the situation produced by the occurrence of each response option. This would be the primary quadrant with which to evaluate the response options.

IV. (O|O) -- Indicates the interaction among possible response options. This possibly could be used to trace the impacts of a mixed strategy, or to evaluate the effects of implementing more than one response.

As in the traditional approaches, each of these quadrants could be evaluated to determine event dominance, sensitivity, and estimator uncertainty. Other forms of analysis would remain essentially the same. These interpretations can only be hypothesized at this time. It will require experimental data to determine their applicability. Therefore, this type of analysis will be attempted using the results from the demonstration exercise.

4. Scenario Generation

Since specific policy options are to be included in the event set, it is questionable as to whether they should be included in the event sequence scenario generation. The occurrence or non-occurrence of a policy option is not determined solely by the situation developments but also by

the decision-maker's perceptions and the evaluations they make. The policy options are explicitly included in order to facilitate more complete evaluation. Based on this information, the decision-makers would then select the option(s) to be implemented (i.e., decide occurrence).

It might also be argued that by including one, or all, options in event sequence scenario generation it would be possible to determine which option(s) should be implemented (based on their occurrence or non-occurrence in the most probable scenario). In other words, generating and ranking scenarios with N options (N = 1,2,3,...,n), and evaluating these scenarios for desirability would indicate which options produced the most desirable outcomes.

However, in a short term situation, the specific event sequence scenario may not be so important. Accurate information is limited, and the unexpected could always happen (including events not specified in the set). Therefore, scenario generation intended to provide specific predictions would be of questionable value unless the problem was clearly understood by the estimators. In view of these considerations, this demonstration will only include the situation developments in event sequence scenario generation.

I. CONCLUSIONS

This chapter described four major approaches to conducting cross-impact analysis, including their basic assumptions, computational procedures, and types of analysis performed.

Based on this discussion, and using consistent evaluation criteria, the approaches were compared and the Mitchell-Tydeman cross-event analysis was selected for us in this study.

Cross-event analysis was selected because, although it required obtaining more numerous subjective estimates, its methodology and underlying assumptions seemed more systematic and thorough as well as intuitively pleasing. In addition, the calculations required in the procedure appeared to be simple enough to perform without using a computer. The Mitchell and Tydeman approach was extended for application in a crisis situation. This extension involved: limiting the time span considered in the analysis, including policy options as discrete events for analysis in the matrix rather than through sensitivity analysis alone, and restricting scenario generation to include only situational developments while excluding policy options.

As indicated in the discussion of the major approaches, several problems may still be encountered in operationalizing this approach. Some of these problems are inherent in conceptualizing the cross-impact technique itself and can-not, therefore, be resolved until data have been collected and analyzed. Such problems include: how estimators can best quantify the interrelationships being sought (proba-bilistically or as correlations), how to interpret estimator responses (as classical probabilities, causal time-dependent

probabilities, or as correlation coefficients), and how
inconsistencies should be treated (ignored, boundary rules,
or fitting methods). The selected technique assumes respon-
dents can think in probabilistic terms, indeed, in terms of
causal time-dependent probabilities, and that inconsistencies
are best resolved using fitting procedures.

Other potential problems arise from dealing with subjec-
tive estimates, and from the methodology used in the selected
approach. These include how best to aggregate estimates,
and how to resolve inconsistencies. Both of these depend on
the form in which the estimates are elicited and the actual
values obtained. Therefore, these problems will be examined
in the context of the selected technique's operationalization.

The next chapter will discuss the actual implementation
process and present the demonstration results. The imple-
mentation process will describe how the demonstration was
structured, and the problems encountered in using the Mitchell
and Tydeman approach. The demonstration results will be used
to evalute the accuracy of the approach's assumptions, and
its potential utility as a crisis decision-aid.

VI. OPERATIONALIZATION

A. INTRODUCTION

Employing cross-impact analysis in an experimental application requires developing and following a logical implementation process. Due to the approach's information requirements and the type of problem proposed, four preliminary steps are necessary for implementation. The first task is to identify a study group to act as expert respondents. Next, a problem environment for analysis has to be constructed. Then, this problem environment, and the approach's purpose, methodology, and information requirements have to be explained to the study group. Finally, a procedure to elicit the group's subjective estimtes has to be devised.

Once the preliminary background has been laid, actual implementation requires collecting and structuring the respondents' estimates into the format required by the cross-event approach, and conducting the analysis. This process includes: identifying candidate events and selecting from these the analysis event set, and aggregating individual estimates into group response values to provide the data for replicating the analysis performed by Mitchell and Tydeman [Ref. 29].[26]

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[26]The purpose behind using group values is two-fold. First, it should reduce instances of pairwise inconsistency [Ref. 29]. Secondly, as proposed by Enzer, the respondents' opinion spread could serve as an estimator uncertainty indicator [Ref. 27, p. 55].

To replicate the cross-event analysis, as extended in the previous chapter, it is necessary to perform two calculation steps. The first step is to compute the event pair ordered outcome probabilities (P_1 through P_8). These values are then used in the second step which calculates the conditional probabilities implied by the respondents' estimates. The conditional probabilities can then be arranged into a cross-event matrix and scenario generation undertaken. These tools are then used to perform the problem analysis.

This chapter describes the implementation design developed for this study. It discusses how the actual operationalization evolved by reviewing the successes and failures encountered in following the designed implementation. Finally, the data collected are presented and analyzed.

B. IMPLEMENTATION DESIGN

The entire operationalization process was designed to follow the demonstration described by Mitchell and Tydeman [Ref. 29, p. 145-147]. Their "event assessment" procedure was used to select an analysis event set [Ref. 23, p. 6-9], the forms for obtaining subjective estimates were taken from the examples contained in Ref. 29, and the equations used in all calculations were from the derivations presented in the same source.

The procedure used to demonstrate cross-event analysis in a hypothetical situation was constructed to follow five phases. Each phase's purpose and structure will be discussed below.

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1. Scenario Construction

To establish the problem environment for analysis a
hypothetical problem scenario was developed. Several con-
siderations influenced this development. Because the problem
was intended to represent an emerging crisis situation, the
scenario had to threaten identifiable national interests,
suggest potential policy options which could be identified
as responses, and involve recognized actors. This last con-
sideration was adopted for two reasons. Using real actors
would provide an actual basis for the respondents' percep-
tions rather than having to structure perceptions by speci-
fying a host of hypothetical historical, social, political,
economic, etc. data in the scenario. Also, using real
actors was expected to make estimation and analysis more
meaningful to the respondents.

To satisfy the above requirements and involve as much
current information as possible in the problem environment,
the scenario was based on developments in South Asia. A
brief justification for this decision will be presented in
the next section which describes the actual scenario pre-
sented to the respondents.

The scenario was presented in four sections to allow
as complete a development as possible. Those sections were:
(1) Background -- described the primary actors, their internal
situations and external relationships. (2) Event Sequence --
listed the hypothetical moves and counter-moves taken by the
various actors. (3) Resulting Situation -- set forth the

actual problem (crisis) to be analyzed and responded to.
(4) U.S. Concerns -- described what appeared to be the
significant U.S. interests in the area. The scenario
presentation was conducted as the second segment of the
design implementation's explanation phase.

   2. Explanation

   This phase described the experiment's purpose and
methodology to the study group. This explanation was in-
tended to help the respondents understand their role in the
experiment. It included: The rationale behind using sub-
jective estimates, the information the respondents would
be asked to provide, the information format, how the infor-
mation would be analyzed, and answered any questions which
arose. In this manner it was hoped to fully involve the
respondents in the project and thereby produce more care-
fully considered responses, while demonstrating to the
respondents the approach's potential as a learning tool.

   The explanation phase involved two segments. The
first described cross-impact theory, its assumptions,
methodology and proposed applications. Once the basic
concepts and their use was understood, the Mitchell and
Tydeman approach was described to the study group. This
presentation highlighted the functions the respondents
would be required to perform.

   The second explanation segment presented and dis-
cussed the hypothetical scenario. This was presented in
four sections, as previously described, in order that the

participants could fully understand the problem elements involved. In an actual application this segment would be optional, as the "experts" could be expected to be familiar with the problem environment. Once the respondents understood the technique and hypothetical problem the third implementation phase was begun.

3. Elicit Estimates

This phase was designed to obtain the subjective estimates used in the problem analysis. Two estimation procedures were developed for this process. The first used a "brainstorming" technique to elicit a candidate event set. Immediately after the scenario discussion the respondents were asked to suggest developments which might occur resulting from the proposed situation. All subsequent estimates were obtained using an individual response procedure.

Once the candidate event set was established the respondents were asked to individually rate each event's initial occurrence probability and significance. This information was used to conduct an "event assessment" and select a manageable event set for analysis. As discussed previously, this procedure was adopted to reduce both the number of estimates and computations required by concentrating on only the "important" events. Individual estimates were then obtained for the causal time-dependent probability relationships (C_1 through C_5) existing in each event pair. These data were intended for use in the fourth implementation phase.

4. Conduct Analysis

The fourth phase was designed to structure the respondents' estimates into the cross-event format and analyze the resulting output. Individual responses were aggregated into group values and used to compute the "cross-impacts" from the formulae developed by Mitchell and Tydeman. This procedure computed the ordered event pair outcome probabilities (P_1 through P_8) and the resulting conditional probabilities for each event pair. At the same time, pair-wise consistency could be checked and resolved if necessary. Because group values were used, instances of inconsistency were expected to be rare.

Given consistent estimates a cross-event matrix would be constructed and scenarios generated. These data would then be analyzed as described in Chpater Three. The analyses to be performed included: For events -- determining dominance, sensitivity, signficance, and uncertainty. For interrelationships -- conducting causal tracings through the event matrix (as discussed in the extension section of Chapter Three), evaluating response options using the matrix and scenarios, performing scenario and sensitivity analysis. The implementation design included presentation of the analysis results as its final section.

5. Presentation of Results

This phase was designed to organize and present the analysis results for evaluation. These results were presented to the study group to close the feedback loop and

complement the learning experience. This phase also
involved the participants in evaluating the cross-impact
technique.

Respondents were asked to suggest possible reasons
for the results obtained, and to assess whether or not
the information derived from their estimates met their
expectations. They were also asked to comment on their
impressions concerning the technique's procedures and poten-
tial utility. This information, and the analysis results,
were used in evaluating cross-event analysis as a possible
crisis decision-aiding methodology. The respondents'
feedback and the actual implementation experience were used
to evaluate the procedure's ease of application, to iden-
tify possible problems and to recommend improvements. The
following section recounts how the designed implementation
actually evolved, and identifies the successes and problems
encountered in operationalizing cross-event analysis.

C. ACTUAL IMPLEMENTATION

The preliminary implementation steps were relatively
easy to accomplish. The study group utilized was a Data
Analysis for Naval Intelligence class being conducted
(Spring Quarter, 1979) at the Naval Postgraduate School,
Monterey, California. The class provided ten respondents
(nine Naval officers and a civilian Professor). The offi-
cers had various types of operational experience in the
U.S. Navy, and were undertaking graduate studies in the

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school's National Security Affairs Department. Thus,
their background was felt to be adequate for demonstration
purposes. All respondents had some exposure to probability
and statistics, organizational management and decision-making,
and various topics in National Security and Intelligence.
In addition, most had kept abreast of ongoing developments
in South Asia. These characteristics simplified the explana-
tion process as no really "new" material had to be covered.

The explanation phase previously outlined consisted
essentially of orally summarizing Chapter Two and the cross-
event analysis section in Chapter Three of this study. The
explanation also reviewed the procedure designed to elicit
the group's subjective opinions. In the second explanation
phase, the study group was led through the scenario developed
for this demonstration. The problem scenario presented to
the respondents will be described below, followed by des-
criptions of the remaining implementation phases.

1. Scenario Development

Developments in South Asia and around the Persian
Gulf have become a focal point for U.S. diplomatic, economic,
and military interests. This increasing interest has been
well documented by noted political scientists and historians.
These authors have detailed increasing U.S. interest in,

and commitment to, the region resulting from numerous interrelated factors.[27]

Some of the primary factors influencing U.S. interests in the area include, increasing U.S. dependence on imported oil and the tenuous supply links through which it is obtained.[28] Another factor is the increased Soviet influence in South Asia, their increasing naval presence in the Indian Ocean, and the purpose behind this presence.[29] A third concern is the continuing tension in the region which seems to keep the relationships in the area in a

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[27]For example, Nadav Safran discusses the U.S. involvement growing out of the Middle East peace process [Ref. 51]. Richard Ullman has examined U.S. policy options in the area in light of continuing tensions and outside pressures [Ref. 52]. Basic considerations for U.S. policy in this area were presented by Campbell and Lenczowski [Refs. 53 and 54]. Inter-regional relationships and super-power roles are examined by Vali [Ref. 55], while Wall has collected papers addressing relevant strategic concerns [Ref. 56]. Many of the interests and concerns developed by these authors are reflected in official U.S. Government documents such as the "Department of Defense Authorization for Appropriations for FY 79" policy statements [Ref. 57].

[28]The oil question is explored by analysts such as Lenczowski and Anthony [Refs. 58 and 59]. Its future implications are examined in a CIA forecast [Ref. 60], which indicates that the situation is unlikely to improve.

[29]Increased Soviet influence and military presence is discussed by Lenczowski [Ref. 61], Hurewitz [Ref. 62], Tahtinen [Ref. 63], and McConnell [Ref. 64]. The dispute over the intentions behind this presence has produced a resultant U.S. policy debate over its military presence reviewed in Daniel [Ref. 65].

state of flux and instability.[30] The complexities of these

problems are indicated by several authors. Although a complete

development of these and associated factors is beyond the

scope of this study, that the region's importance is an area

for continued policy analysis should be self-evident.

Further, recent developments in several South Asian states have

thrust the region's problems more prominantly into public view.

Among those recent developments is the pro-Soviet coup

in Afghanistan coupled with signs of increased Soviet influence

within the new regime and subsequent internal turmoil. Another

situation causing increased concern was the overthrow of the

Shah of Iran and resulting uncertainty over the direction in

which the new government would evolve. Adding to general con-

cern for the course of the Iranian situation has been the

centrifugal forces set in motion by Kurdish and Arab national-

ists as well as politically liberal forces within the country.

In addition, the execution of Bhutto by Pakistani authorities

has increased internal dissent in that country. This dissent

is significant because it occurs during a period of tension

between Afghanistan and Pakistan concerning reputed Pakistani

support for dissident tribesmen challenging the Taraki regime

in Afghanistan.[31]

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[30]A regional perspective on area tensions is presented by
Amire [Ref. 66], and Misra [Ref. 67]. Burrell and Cottrell
[Ref. 68] explore specific problems faced by the states of
South Asia.

[31]These developments are being continuously reported in
magazine and newspaper articles. Articles describing these
specific developments include: On the Soviet involvement and
turmoil in Afghanistan; Sherwell, Chris, "Fighting May Boost
Soviet Presence in Afghanistan," The Christian Science Monitor,
p. 6, Dec. 29, 1978, and Sherwell, Chris, "Soviet Union Mired

For these reasons it was decided to develop a problem scenario involving relations in South Asia. The study group would be familiar with the basic situation existing in the area, and could easily identify important (as well as plausible) developments reflecting U.S. interests and possible response options. The actual scenario was developed as follows.

a. Background

This section, supported with newspaper clippings, presented the current situation existing within and among the three regional actors being considered. Afghanistan was described as having recently undergone a pro-Soviet coup. Its military was identified as a prime factor in maintaining political control. The country's administrative bodies, including the military, were reported to be heavily influenced by Soviet advisors. In addition, the state's internal situation was characterized as being plagued with anti-government groups, consisting mainly of Moslem tribesmen in the rural areas.

The situation in Pakistan was described as involving increased internal dissent resulting from Bhutto's execution. Problems were also reported to be developing from the influx of Afghan refugees. In addition, the Pakistani military was described as poorly equipped and preoccupied with the Indian threat to Kashmir.

in Afghanistan," The Christian Science Monitor, p. 3, May 24, 1979. On Iran's internal power struggle; Godell, Geoffrey, "Leftists Step up Struggle for Control of Iran Revolution," The Christian Science Monitor, p. 3, Feb. 16, 1979, and Allaway, Tony, "Kurdish Unrest Tests New Iran," The Christian Science Monitor, p. 3, Mar. 22, 1979. On Pakistan; "Delayed Decision on Bhutto to Affect Pakistan Deeply," The Christian Science Monitor, p. 4, Mar. 19, 1979, and Marshall, Tyler, "Indian Subcontinent Faces Pressure for Arms Buildup," The Los Angeles Times, p. 1, April 22, 1979.

Iran's current government was described as
disorganized, composed of several rival factions, and
challenged by elements (including leftists and ethnic
minorities) desiring more control. The effectiveness and
loyalty of Iran's military was also brought into question,
due to its history of supporting the Shah and the execution
of several important leaders. This development stressed the
fact that authority in Iran could still be considered to
be in a state of flux. Finally, Iran's historic role in
controlling disputes between Afghanistan and Pakistan
concerning the territory of Baluchistan was mentioned.
Using this simplified background discussion as a basis,
a hypothetical sequence of developments was proposed to
the study group.

     b. Event Sequence

        - Tribesmen in Baluchistan (South Afghanistan)
begin a national autonomy movement. This movement
receives some support from related tribes in Iran and
Pakistan.

        - Clashes occur between Afghani government
forces and rebel tribesmen in Baluchistan.

        - The Afghani government dispatches additional
troops to control the area. These troops are Soviet
supported, but the extent of this support is unknown.

        - These forces drive the majority of the rebels
across the border into Iran and Pakistan.

        - Both sides (rebels and Afghani troops) begin
cross-border raids. By this time the majority of the
Afghan army is committed.

        - Afghanistan charges that Iran and Pakistan
are aiding the rebel forces. The Afghan government vows to
defeat any outside threat to its territorial integrity.

The Soviet Union supports this delcaration and offers to increase assistance to Afghanistan.

- Iran authorities deny the Afghani charges and state that increased Soviet involvement would only worsen the situation. Pakistan charges the Soviet Union with trying to precipitate a crisis in the region, and requests U.S. aid.

- Regular Afghani forces clash with Iranian border troops. This clash erupts into uncontrolled shelling along the border.

- Baluchistan rebels call on Muslim states for support against the communists, suggesting a "holy war" be launched.

- Iranian leftists, reportedly supplied by the Soviets, begin a terrorist campaign to oust the Ayatollah's government.

- Iran announces support for rebel tribesmen and launches a "limited" invasion to pacify the area, and expel "expansionist" communists.

- *Pakistani forces join the conflict.*

- The Soviet Union sends troops to Afghanistan which check the Iranians. Reports indicate the Soviets have mobilized on Iran's border, that their agents are agitating Iranian Kurds, and that they have sent a secret mission to Iraq.

- Soviet and Afghani forces press attack to the original Afghan border, but show no signs of halting. Steps are being taken to set up a "puppet" government for Baluchistan. Indications are that Soviets and Afghanis may attempt to include Baluchistan land in Iran and Pakistan under control of an "autonomous" Baluchi government.

Based on these developments, the following situation was proposed to exist in South Asia. This situation described the crisis problem to be evaluated using cross-event analysis.

c. Resulting Situation

- Open warfare exists in the area south of Afghanistan extending into Iran and Pakistan. This fighting involves Afghanistan, Iran, Pakistan, rebel tribesmen, and (reportedly) some Soviet forces.

- The Soviets have mobilized along Iran's border and are conducting secret talks with Iraq.

- Iranian Kurds and leftists (separately) are almost in open revolt.

- India has mobilized along Pakistan's border, to "prevent the conflict from spilling over."

- Chinese troops have mobilized in Sinkiang in response to "Soviet aggression, and to demonstrate support for the Baluchistan People's Movement".

To guide the respondents in proposing candidate events the following "probable" U.S. concerns were also presented.

d. U.S. Concerns

- The current conflict threatens navigation in the Straits of Hormuz. In addition, the fighting is close to the main oil producing region in Iran, threatening the security of those fields.

- The Soviet Union may extend its influence to the Indian Ocean if it manages to sponsor a client state of Baluchistan. This would permit both overland access to the Indian Ocean and possible naval basing rights.

- The current turmoil directly threatens U.S. civilians in the area and, to a lesser extent, U.S. economic interests.

- The potential involvement of India and China and possible direct Soviet intervention suggest a major confrontation may be developing.

This scenario provided the background against which the respondents were asked to suggest a candidate event set, and formulate the required subjective estimates. This process will be described in the following section which details the implementation design's third phase as it actually developed.

2. Elicit Estimates

The next task undertaken in the demonstration required establishing a candidate event set. Before the group was asked to brainstorm possible developments, several procedural points were reviewed. The study group was reminded that suggested events be considered as developing from the given situation. Enzer's criteria for including events in the set were also reviewed. These criteria stress that candidate events be (1) important to the situation, (2) of uncertain outcome, (3) causally related, and (4) specific. Finally, the event formulation rules proposed by Mitchell and Tydeman were reviewed to assure the suggested events could be clearly understood by the group. These procedural points were discussed in Chapter Two.

a. Establishing the Event Set

Once the group understood the required event formulation method, a brainstorming session began. As events were suggested they were recorded and posted before the group. This process continued until it became apparent that the participants had exhausted all their ideas. A brief discussion session then was allowed to clear up any uncertainties. Twenty-nine candidate events were proposed during this session. Ten of these represented possible U.S. responses to the situation, the remainder represented situation developments. These events are presented in Appendix A.

In order to select an analysis event set the
group was next asked to provide the subjective evaluations
required for Mitchell and Tydeman's "event assessment"
procedure. These inputs consisted of two estimates. The
first required the respondents to evaluate each event's
initial occurrence probability. These probabilities were
collected individually by having each respondent score every
event on the following scale. Each evaluation was to be
made without considering the influence any other event in
the set might have on the situation.

TABLE TWO

EVENT PROBABILITY DESCRIPTIONS AND RATINGS

STATEMENT	RATING
Won't Occur	.05
Very Unlikely	.15
Unlikely	.30
Fifty-Fifty	.50
Likely	.70
Very Likely	.85
Certain	.95

The second estimate required respondents to
evaluate each event's significance should it occur. An
event's significance was defined as the influence it would
have on the overall problem situation, assuming it did
occur. These ratings were based on the following scale,
and were again collected individually.

TABLE THREE

EVENT SIGNIFICANCE DESCRIPTIONS AND RATINGS

STATEMENT	RATING
No Importance	1
Some Importance	2
Important	3
Very Important	4
Critical	5

This procedure produced ten values under each criterion for each of the twenty-nine events. These individual scores were aggregated and used to produce an impact rating for each event. The twenty-nine candidate events and their probability, significance, and impact ratings are contained in Appendix A.

Several problems were encountered during this estimation procedure which were unanticipated in the problem design. While eliciting candidate events two tendencies were noticed which seemed to inhibit the formulation process. In brainstorming, the respondents seemed to concentrate on a suggested event and propose subsequent events which would develop should the first event occur. Often this process would lead far afield until interrupted by the facilitator interjecting an alternative event. On other occasions, an event's suggestion seemed to elicit the proposal of a response event aimed specifically at the first event. Another problem encountered stemmed from the respondent's experience level or knowledge.

Some respondents seemed to be intimidated by the ease with which other respondents formulated and justified suggested events. A few respondents stated they felt unqualified to participate, and questioned the validity of their future estimates given their lack of equal knowledge concerning South Asia. These problems seem to be inherent in the "brainstorming" process.

In future applications it is felt that using trained or experienced facilitators could reduce the problem of respondent intimidation, and better control the brainstorming process. In addition, research using the delphi procedure indicates that having respondents rate themselves on their confidence in answering questions provides a criterion with which to weight individual responses to produce improved group values [Ref. 13]. This method might be incorporated in future cross-impact applications.

The fact that suggested events often led to related events being suggested indicates a basic cross-event assumption may be unfounded. The approach operates on the theory that respondents can think in terms of discrete events. Based on this assumption respondents are asked to provide initial probability and significance estimates for each event independently. However, during the brainstorming process, respondents exhibited a tendency to propose events in an iterative manner. This suggests that the group may find it difficult to conceptualize relationships in terms of discrete events, and therefore may conceive of

of related probability and significance questions inter-dependently, or as contingencies. This in turn indicates that another approach to quantifying estimates may be more appropriate. This point will be developed more exten-sively in the next chapter.

Other problems were encountered when the indi-vidual estimates were aggregates to produce the impact ratings. In their procedure, Mitchell and Tydeman use a weighted product of each event's probability and signifi-cance scores to produce its impact rating. This procedure was found to produce inadequate results in this demonstra-tion. The results obtained seemed to disguise the impact assigned an event which received a combination of a low and high rating on the two criteria evaluated. A simpli-fied, hypothetical example may help to illustrate this point.

Assume three countries are rated on their mili-tary potential by aggregating scores for their Army, Navy, and Air Force. Using a multiplicative index produces the following results.

FIGURE 4

RESULTS OF A MULTIPLICATIVE INDEX

COUNTRY	ARMY (x)	NAVY (x)	AIR FORCE (=)	MILITARY POTENTIAL
A	5	2	3	30
B	5	1	3	15
C	5	0	3	0

Using the same values with an additive index seems to produce a more realistic measure.

FIGURE 5

RESULTS OF AN ADDITIVE INDEX

COUNTRY	ARMY (+)	NAVY (+)	AIR FORCE (=)	MILITARY POTENTIAL
A	5	2	3	10
B	5	1	3	9
C	5	0	5	10

Another, less significant, problem developed because two different scales were employed in the "event assessment." Probability values were quantified between zero and one, while significance scores ranged from one to five. This further distorted the multiplicative index. As a result the impact scores produced an analysis event set which did not seem to accurately reflect the event's relative importance. To overcome this problem two corrections were introduced to the aggregation procedure.

The significance ratings were rescaled to fall between zero and one. The final ratings employed were: 5=.95, 4=.7, 3=.5, 2=.3, and 1=.05. Then the individual probability and significance ratings were summed to produce an individual event impact rating. All three ratings were then averaged to produce a group or mean score, and the standard deviations were computed for

each measure.   These are the values presented in Appendix
A.

This correction is not without conceptual
limitations. The assumption implicit in summing the two
evaluation measures is that both probability and signifi-
cance are equally important in determining an event's
impact on the problem environment. It is doubtful whether
this assumption would hold up under rigorous examination.
It appears that an event's significance would be a more
important consideration than its occurrence probability.
This is because an event's impact has no meaning should it
not occur, therefore, it only becomes important from a
policy standpoint once it occurs, and this importance
derives from its significance to the situation. This prob-
lem relates to Gordon's discussion of the complex factors
which make up an event's cross-impact [Ref. 24]. Presently
there exists no algorithm relating the many factors (such
as probabilities of "feasibility" and "pursuit", and event
significance) which compose an event's impact. As a result
simple summing was the only approach which could be readily
applied.

Candidate events were ranked by impact scores
and six events selected to form the analysis set. A final
ranking by event impact scores is contained in Appendix A.
Because one purpose of the demonstration was to examine the
cross-impact technique's applicability to evaluating specific
policy response options these six events were not chosen from

the top ranked candidate events. The six top ranked events

included only one event identified as a response option

(number three). This was because, while most response

events were evaluated as having high initial probabilities,

their significance was evaluated as being relatively low.[32]

To obtain a matrix containing an equal number of response

events and situation development events, the events were

separated and the top three chosen from each category.

The analysis event set and the mean initial

probabilities are presented below. Six events were used

because this was felt to be the maximum number which could

be effectively manipulated by hand. It should be noted that

the initial probability values have been rounded to two

decimal places. The averaging technique used retained three

decimal place values for comparison purposes. Because

these values were averaged subjective estimates, this

degree of accuracy would not be jsutified for use in the

actual demonstration. This event set formed the basis for

the remaining individual estimates, that is, the five

causal time-dependent relationships developed by Mitchell

and Tydeman.

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[32]This result is interesting due to its implications.
Although the U.S. is assumed to have an extensive number
of responses available which could be employed in a given
situation, the respondents obviously felt that the majority
of these would be ineffective in this case. Of the three
response options included in the analysis, only one had a
significance score comparable to that of the situation
development events.

TABLE FOUR

SELECTED EVENTS

No.	STATEMENT	Avg. P_i
22	Soviet/Afghan forces gain control of Baluchistan.	.60
28	Soviet Union builds up Indian Ocean squadron.	.80
23	Soviet Union airlifts supplies to Afghanistan.	.72
3	United States deploys CTF to Indian Ocean.	.76
9	United States evacuates civilians from area.	.84
8	United States offers to negotiate a cease-fire.	.64

b. Estimate Relationships

The six-event set produced fifteen possible event pairs which required further estimation. The required estimates were the five time-dependent probabilities (C_1 through C_5) which assessed occurrence, non-occurrence, and joint occurrence. Thus, seventy-five estimates were required from each respondent.

In order to systematically produce and collect these estimates, response forms were duplicated from the examples provided by Mitchell and Tydeman [Ref. 29, p. 146-147]. The forms used are reproduced on the next page.

FIGURE 6

FORM FOR EXTIMATING C_1 AND C_3

Would the prior occurrence of event #   cause your estimate
of the Probability of event #   to:

Increase   Stay the same   Decrease

If your estimate of event #   probability is changed (increased
or decreased) is the magnitude of the change:

Only Slight   A Little   A Fair Bit   A Lot   Sufficient to
                                                       make event #
                                                       certain or
                                                       impossible

    5   10   25   50   100
(% of total possible change)

FIGURE 7

FORM FOR ESTIMATING C_2 AND C_4

Would the prior non-occurrence of event #   cause your
estimate of the Probability of event #   to:

Increase   Stay the Same   Decrease

If your estimate of event #   probability is changed (increased
or decreased) is the magnitude of the change:

Only Slight   A Little   A Fair Bit   A Lot   Sufficient to make
                                                       event #   certain
                                                       or impossible

    5   10   25   50   100
(% of total possible change)

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FIGURE 8

FORM FOR ESTIMATING C_5

Assuming <u>both</u> events #   and #   occur within the next 14 days

    Event   is certain to occur first

    Event   is very likely to occur first

    Event   is likely to occur first

    Event   and event   are equally likely to occur first

    Event   is likely to occur first

    Event   is very likely to occur first

    Event   is certain to occur first

These forms were organized by selecting the
first event in the set and pairing it with the remaining
five events. The next series of estimates paired the second
event with the remaining four events and so on until all
fifteen event pairs had been specified. Because there were
seventy-five total estimates, the forms were delivered to
the respondents in two batches. Each respondent was given
two days to complete each batch. The forms were then
collected and sorted by event pair and the relationships
assessed. The ten responses for each relationship were
averaged to produce a mean score for each relationship.
These scores are contained in Appendix A.

Several complaints were voiced by the respon-
dents concerning this estimation procedure. This approach
made the estimation process monotonous. Three questions
were repeated with only different event numbers

being inserted to complete the seventy-five data points.

In addition, the question wording was felt to be tortuous,

specifically through use of the terms "prior occurrence",

and "prior non-occurrence".

These problems result from manually replicating

the cross-event procedure. It was not possible in the

time available to devise an optimal question format for

each event pair. Such a format could have incorporated

the event statements within the question. For example

the following formulation for event pair (28,3) would

probably have been more acceptable:

> "Assuming the Soviet Union builds up its
> Indian Ocean fleet, would you estimate
> the probability that the U.S. deploys
> a CTF to the Indian Ocean to:"

and for non-occurrence:

> "Assuming the Soviet Union does not
> build up its Indian Ocean fleet, would
> you estimate the probability ..."

Such a format could obviously be constructed for each

event pair. Several advantages might stem from adopting

this approach. The more precise wording explicitly

incorporates the event statements being considered. The

causal time-dependent nature of the relationship being

explored is implicit in the question without employing

phrases such as "prior occurrence." As a result the responses

obtained might be more accurate and consistent, however,

this fact cannot be validated without further analysis of

how respondents interpret questions.

Another problem encountered in the procedure
was not voiced by the respondents, but was hypothesized
to account for the responses obtained when the group values
were analyzed. The analysis of the responses presented in
the next section found that every event pair was inconsistent
in terms of the P_1 through P_8 ordered outcome probabilities
computed. This problem was felt to result, at least par-
tially, from the sequence in which estimates had been
obtained.

The sequence used in this demonstration was
selected because it systematically specified all the event
pairs. This was necessary to insure that all respondents
received the proper forms and thus provided all required
estimates. However, this may have been an inappropriate
way to procede through the event pair set for estimation
purposes. In addition, the five relationships being esti-
mated were not presented to the respondents in order. The
joint occurrence question (C_5) being retained until the
end of each series (Event 1|Event 2,..., event 6) of the C_1
through C_4 questions.

As the respondents answered the questions in
the order of presentation, it is possible that they lost
track of the values previously specified. It is also
possible that the respondents were prevented from con-
sidering their previous responses concerning event pairs
which might have been felt to be related to each other.
Once again these possibilities cannot be verified without

experimental analysis. No doubt, there is an optimal way to present the event set for estimation.

This conclusion is based on two arguments presented in the cross-impact theory discussion. First, Enzer suggested that probabilities of conditional relationships were bounded by the probabilities previously specified for that event pair. If this is true then this condition could also apply to the time-dependent causal probabilities. The second argument is even more basic to cross-impact theory.

Gordon suggested that most events are related in some way. Enzer approached this conclusion in his discussion of coupling. It therefore seems reasonable that the discrete events composing a set may all be coupled in some way. This, it should be noted, is not the concept of higher order interactions which Turoff attempted to measure, but refers to direct relationships among all events in the set. Assuming such a situation is present, then in order to produce a consistent set of estimates, a respondent needs to be able to review and incorporate not only his previous estimates within an event pair but among event pairs as well.

In summary, the problems encountered and suspected in this process were: (1) monotony, (2) imprecise question wording, and (3) inappropriate question sequence. To overcome these problems it would be necessary to devise an estimation procedure which: (1) formulates questions using the event statements, (2) develops a more exact question

structure, (3) allows estimators to review their responses as they estimate, and (4) allows estimators to compare their responses across related event pairs.

One possible approach to overcoming these problems might be to use an interactive computer program to elicit estimator responses. This approach was demonstrated by Turoff. As proposed here, the program would allow the respondent to make estimates on the basis of responses concerning other estimates. Obvious extensions to this approach include computing probability boundaries as suggested by Dalkey, and displaying results to allow re-estimation as suggested by Turoff. Using an interactive computer would aid in obtaining consistent probability estimates (this problem will be returned to in a later section). It might also provide useful data for determining how respondents interpret questions posed, and for devising an optimal estimation sequence.

Despite the problems encountered by the respondents, and because the suspected problems were not immediately apparent, the respondents' estimates were collected and averaged as planned. These values formed the input for computing the eight ordered outcome probabilities for each event pair.

3. Analysis

The next phase in the demonstration was to replicate the analyses performed by Mitchell and Tydeman as extended for this application. This required that the responses

obtained be converted into conditional probabilities, and
that these be used to construct a cross-event matrix and
generate scenarios. This section will describe the compu-
tational procedure used and discuss the results obtained.

     a.   Computational Procedure

       Once the respondents' estimates were averaged
and the standard deviations for each relationship computed,
mean values were used to compute the ordered outcome proba-
bilities. The P_1 through P_8 values for each event pair
were calculated using the formula derived by Mitchell and
Tydeman as presented in Section E of Chapter Three. These
values were used to compute the conditional probabilities,
however, unlike the Mitchell and Tydeman demonstration,
every event pair was found to have inconsistent results.

       According to Mitchell and Tydemand inconsistency
exists when any outcome probability is negative [Ref. 29,
p. 142]. In fact pairwise inconsistency from a probabilistic
standpoint is manifested by a value >1 or <0, and is indi-
cated when the common factors α, β, and γ exceed unity or
become negative. The calculated outcome probabilities for
each event pair are presented in Appendix B.

       The cross-event procedure uses a minimum stan-
dard deviation fitting technique to resolve pairwise incon-
sistency. This technique, as described in Chapter Three,
was felt to be inappropriate for use in this demonstration.
One reason was that it would require an excessive amount of
time to resolve fifteen inconsistent sets. Also, the

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technique, as demonstrated by the developers in a case resolving individual inconsistency, zeroed the inconsistent values. Of the fifteen event pairs developed in this study, over half the outcomes in twelve pairs were inconsistent while six pairs had seven or more inconsistent values. As a result, it was felt that the fitting technique would destroy too much potentially useful information.

Even though the ordered outcome probabilities were apparently inconsistent, it was still possible to compute conditional probabilities using the formulae devised by Mitchell and Tydeman. These conditional probabilities would doubtlessly also be inconsistent from a probabilistic standpoint, however, in the cases where one conditional probability appeared consistent it would be possible to employ Enzer's boundary rule to resolve the second probability. As in the case of the fitting technique, this procedure was expected to destroy at least half of the potential information. In addition, the boundary rule could not be applied in cases where both conditional probabilities appeared to be inconsistent.

Because the demonstration results were apparently inconsistent, it was not possible to produce all the data required for the intended analysis and evaluation. Having only the ordered outcome probabilities precluded any attempt to determine event dominance and sensitivity. Nor was the required data produced for completing the cross-event matrix and undertaking scenario generation. Therefore, it was not

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possible to conduct the analyses which use these tools. In particular, the demonstration could not be used to determine the validity of the proposed extension which included discrete policy options in the event matrix. Even so, it is still felt that this was a practicable extension, given a workable cross-impact format, which could become a useful analytical tool.

Two alternatives for solving the inconcsistency problem seemed to present themselves. The designed study could be continued by arbitrarily specifying a consistent set of values. This alternative would have ignored the study's intended purpose of assessing the utility and effectiveness of cross-impact analysis as a possible decision-aid by forcing the methodology to work rather than examining its problems and their implications.

The second alternative was to examine the apparent inconsistencies to determine if they were in fact inconsistent. It would then be possible to determine; a) why the information was inconsistent and what corrective measures could be taken, or b) why the information appeared to be inconsistent, and how it could be used if it was in fact consistent. This alternative was selected. The approach used will be described in the following section.

b. Exploring the Inconsistency Dilemma

The first task in exploring the inconsistency problem was to determine if the demonstration results were in fact inconsistent. To do this the cross-event approach's

assumptions and implications were re-examined. It was obvious that the collected data provided enough information to rank the ordered outcome probabilities. If the outcome probabilities were considered as an eight element set there were $P_8^8 = \frac{N!}{(N-R)!} = 8!$ possible rank combinations. If it could be shown that the fifteen combinations obtained during the demonstration formed a pattern displaying some underlying logical consistency apart from the consistency demanded by the constraints of probability theory, and if this pattern occurred in a statistically significant number of cases, then the responses could be demonstrated to provide useful information which might otherwise be masked by routine cross-impact analysis techniques.

The respondents had been asked for causal, time-dependent estimates which were used to compute ordered outcome probabilities. The estimates were obtained by assuming the certain occurrence or non-occurrence of an event (cause) and assessing the change in probability this produced in another event's probability (effect). The out-come probabilities computed using these estimates were time sequences, which retained this cause and effect structure. The eight ordered outcomes could, therefore, be paired by opposite cause.[33] This resulted in pairing the following

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[33]Actually, several pairing methods were possible. For example: Transpose (i,j with j,i), opposite cause (i,j with ī,j), opposite effect (i,j with i,j̄), and opposite cause and effect (i,j with ī,j̄). However, since the relationship being estimated assumed known cause (prior occurrence or non-occurrence), in effect holding cause constant, the opposite cause pairing was considered more relevant for testing.

outcomes: $P_1 - P_3$ (i,j with $\bar{I}$,j), $P_2 - P_4$ (i,$\bar{j}$ with $\bar{I}$,$\bar{j}$), $P_5 - P_7$ (j,i with $\bar{j}$,i), and $P_6 - P_8$ (j,$\bar{I}$ with $\bar{j}$,$\bar{I}$). If the respondents had been consistent, it could be argued that the pairing of probability ranks by cause would reveal some logical pattern. To accept this argument, the pattern would have to appear more frequently than could be expected by random chance.

Upon pairing the probability rankings in the fifteen cases (one for each event pair) by cause, several patterns were noted. These are depicted in Appendix B. As stated above 8! combinations are possible. To show consistency a pattern would have to permit prediction (i.e., by knowning one outcome probability's rank it would be possible to determine its pair's rank.) By this criterion one obviously consistent pattern was noted and termed the "Chinese Box".

The "Chinese Box" pattern paired the first and last, second and seventh, third and sixth and, fourth and fifth ranked probabilities. The pattern was intuitively pleasing as it indicated that the respondents had ranked last the opposite cause to the cause ranked first, ranked next to last the opposite cause to the cause ranked second, and so forth. This pattern implied that some logical consistency existed in the way respondents linked cause and effects in the demonstration situation. A second consistent pattern could also be identified although it was intuitively less rigorous. This was actually a family of patterns which

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existed when one pair and its opposite pair were located in the upper half and lower half of the scale respectively. This also implies some degree of consistency although it does not allow exact prediction. The "Chinese Box" pattern was selected for testing because it was more rigorous, and could be expected to occur less frequently by random chance than the simple upper-lower split.

A "Chinese Box" occurs when one of the outcome pairs is ranked in position one through four before its pair is ranked in the corresponding position from the bottom up (eight to five). Thus there are $P_4^4 = \frac{4!}{0!} = 4!$ combinations which produce this pattern. But since P_1 can be replaced by P_3, P_2 can be replaced by P_4, P_5 can be replaced by P_7, and P_6 can be replaced by P_8, the actual number of combinations is given by $4! \times 2 \times 2 \times 2 \times 2 = 384$. Thus the theoretical probability of observing a "Chinese Box" can be determined as $384/8! = .0095 \doteq .01$. During the demonstration the following results were obtained. In the fifteen cases, eight obviously inconsistent sets occurred and seven apparently consistent sets were observed. This produces an experimental frequency of .47. Two tests were used to determine if this result was statistically significant.

The Kolmogorov-Smirnov one sample test provided the following results for a sample set of N = 15 cases, and two categories (consistent, inconsistent) [Siegel, 1956, p. 47-52].

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$F_O(X)$ = the theoretical cumulative distribution of cases

$S_{15}(X)$ = the observed cumulative frequency distribution of a random sample of 15 cases

D = the maximum deviation between $F_O(X)$ and $S_{15}(X)$ or $|F_O(X) - S_{15}(X)|$

The critical value for D at the .01 significance level is .404 for 15 cases [Siegel, 1956, Table E, p. 251].

TABLE FIVE

CONSISTENCY PATTERNS IN 15 CASES

	OUTCOME EVALUATED AS	
f = number of cases in each category	CONSISTENT	INCONSISTENT
	7	8
$F_O(X)$	.15/15	15/15
$S_{15}(X)$	7/15	15/15
$D = |F_O(X) - S_{15}(X)|$	6.85/15 = .456	0

Since D = .456 > .404, this finding is evaluated as significant at the .01 level. However, as in most cases involving a small N this conclusion would not be justified if the number of consistent outcomes was reduced by one. For six consistent outcomes D = .39 and is only significant at the .05 level where the critical D is .338.

As an additional check on the statistical significance of this outcome and in order to determine the probability

that this demonstration represents a random sample, the
Binomial Test was applied [Siegel, 1956, p. 36-42]. In
this test:

> P = proportion of cases expected to be consistent
>
> Q = 1 - P = proportion of cases expected to be inconsistent
>
> N = number of cases
>
> x = number of observed consistent outcomes

The probability of observing exactly seven consistent out-
comes is given by:

$$p(x) = \binom{N}{x} P^x Q^{N-x} = p(7) = \binom{15}{7}(.01)^7(.99)^8$$

$$= .0000000001$$

where

$$\binom{15}{7} = \frac{15!}{7!8!}$$

Thus $p(7) \doteq 0$, and the probability of observing five or more
consistent outcomes can be computed similarly as $p(x \geq 5)$
= .0000004. Since these tests both indicate that the observed
frequency of consistent rankings (.47) was significant,
the following conclusion was reached.

Although all event pairs were evaluated as being
inconsistent using the cross-event approach's probabilistic
criteria (any P_1 through P_8 < 0 or > 1), in actuality seven
cases were consistent when the probabilities were ranked

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and paired by opposite cause. The implications of this
finding will be addressed in the concluding chapter.

D. CONCLUSIONS

This chapter described the implementation process de-
signed to demonstrate cross-event analysis in a hypothetical
crisis situation. Several problems were encountered in
putting the design into effect. During the estimation
phase it was discovered that a "brainstorming" session
could get out of control and range far from the intended
situation, or intimidate some respondents. It also seemed
that the respondents had difficulty thinking in terms of
discrete events. Furthermore, the method suggested for con-
ducting "event assessment" was found to be inappropriate
because it used two different scales and a multiplicative
index.

Other problems were encountered in estimating the
interrelationships between event pairs. Some problems arose
due to limitations in the implementation design, specifically,
the problems of monotony and imprecise question wording.
Because inconsistent probabilities were obtained, addi-
tional problems were suspected to exist in the estimation
process. These problems involved the sequence in which the
estimates were asked for and the fact that respondents might
have lost track of their previous responses in the course
of completing the forms. Finally, the way in which rela-
tionships were quantified was suspect.

To overcome these problems, several solutions were proposed. An experienced facilitator was recommended to control the brainstorming process. In addition, incorporating a method for respondent self-evaluation was suggested to permit weighting estimates for reliability. Because respondents apparently had difficulty conceptualizing discrete events it was suggested that they thought in terms of inter-relations or contingencies.

Improvements to the "event assessment" process included, using similar scales for the measures being combined, and adopting an additive impact index rather than a multiplicitive one. It was also noted that further research into the components which constitute an event's impact, and their relative importance was also desirable in order to devise an appropriate algorithm for combining the various measures. Overcoming the problems of monotony and imprecise question wording in assessing interactions requires devising an improved question format.

This improvement could be realized utilizing an inter-active computer program. This would also allow respondents to review their estimates, and could be extended to provide probability bounds for estimates, and to present respondents with a display of the results obtained from their inputs. Such programs have been demonstrated in several applications reviewed in this study. The other problems suspected in the estimation process were only hypothesized and could not be

verified without additional study. Data regarding question sequence and respondents' thought processes could be collected while using the interactive computer program.

Once the implementation problems were discussed and possible solutions suggested, the experiment results were presented and analyzed. It was found that the ordered outcome probabilities for each event pair, as computed from the respondents' estimates using the rules of probability theory, contained inconsistent values. However, when the information required from the respondents was presented as causal, time-dependent estimates, and the information contained by the computed output was presented as the respondents' view of the sequence in which the two paired events were likely to occur, another interpretation was possible.

The ordered outcome values could be ranked and paired according to opposite cause. In seven of the fifteen cases, this procedure produced a pattern suitable for exact prediction. This "Chinese Box" pattern was shown to be intuitively pleasing as an indication that the respondents had been logically consistent in their responses.

In order to determine if this result was statistically significant, two tests were applied to the data. The Binomial Test showed that the probability of obtaining more than five "Chinexe Boxes" was close to zero, while the Kolmogorov-Smirnov one-sample test showed that the results obtained were significant at the .01 level. Therefore, it

was decided that the respondents had been consistent in almost half of the event pairs, and that the apparent inconsistency in those cases resulted only because the values computed did not produce valid probabilities.

The next chapter will explore the implications of this finding for the future use of cross-impact analysis. This will require evaluating the approach's basic assumptions regarding how interactions are quantified and manipulated. This evaluation will draw on the impression formed during the brainstorming process that respondents may think in terms of interrelations or contingencies. The future utility of cross-impact analysis as a crisic decision-aid will be assessed using the experience gained in applying the technique in this demonstration, and through drawing on the feedback comments made by the study participants. Finally, it is hoped to suggest possible improvements to the technique, and to recommend further areas for study.

V. CONCLUSION

A. INTRODUCTION

Aside from the several minor problems encountered in implementing the selected cross-impact analysis technique in a hypothetical situation, this study revealed a major conceptual limitation in the technique. This conceptual problem underlies a basic assumption which must be adopted in any cross-impact approach. The problem stems from determining what interpretation should be applied to the estimates provided by the expert respondents. This problem relates to determining how individual thought processes actually work, and how complex relationships are conceptualized. The problem underlies any methodology which attempts to employ subjective estimates.

In reviewing cross-impact analysis' basic concepts and assumptions it was noted that several interpretations could be applied to subjective estimates, depending on the assumption made concerning the way individual's interpret and analyze unfolding situations. These alternative interpretations can be grouped into at least two main categories. The first, which was pursued in this study, viewed the estimates as causal probabilities. Under this interpretation, individuals are assumed to be essentially Bayesian information processors.

The second interpretation views subjective estimates as quantified variation estimates, or, as directly describing how a change in one variable produces a change in another variable. Under this interpretation, an individual is assumed to be a more complex information processor than is described by the Bayesian model. This interpretation was used in the Turoff approach, which represented the results obtained from the respondents' estimates as analogous to correlation coefficients.

How the question of interpreting subjective estimates is resolved forms the basis for the methodological approach used in cross-impact analysis. The assumed interpretation determines how inconsistency is identified and corrected. It also influences the method used to obtain estimates and produce cross-impact factors. For these reasons, determining the appropriate assumption to be used in interpreting estimates is essential to performing reliable, useful cross-impact analysis.

The results obtained in this study indicate that a probabilistic interpretation of estimates may not be appropriate. It was demonstrated that, although the ordered outcome values were inconsistent as probabilities, a significant number of event pairs contained an outcome pattern which indicated that a consistent thought process had occurred. Additionally, during event generation, respondents showed a tendency to think in terms of contingencies or interrelations.

This chapter will address the question of how respondents answer the cross-impact questions posed in light of the study results. This discussion will focus on the alternative interpretations proposed, and how each of them may be used in future cross-impact analysis applications. The final section of this chapter will discuss the technique's use as a decision-aiding methodology as it is currently structured. This discussion will highlight the technique's strengths and weaknesses in problem analysis.

B. INTERPRETING RESPONDENT ESTIMATES

Of the two interpretations proposed, the most frequently employed is probability. The inherent advantages of this interpretation were discussed in the technique selection section of Chapter Three. These advantages were primarily methodological in nature. The probabilistic assumption provided a method for determining if respondents' estimates were consistent. Furthermore, by using probabilistic relationships, a well structured algorithm for manipulating estimates was also developed.

1. Probabilities

Using probability values restricted the estimated and computed values to a range between one and zero. Several procedures were designed to correct values which exceeded these bounds. All of these procedures essentially zeroed or made unity the extreme values. As demonstrated in this study, use of these correction procedures could

destroy much information. This is true especially when a large number of extreme responses are obtained. This study also demonstrated that bounding the estimated values to normal probability limits can disguise otherwise consistent results. A possible explanation behind the excessive number of extreme responses is that the respondents do not easily conceptualize events and their interactions in probabilistic terms.

This problem could be reduced if respondents were trained to make probability estimates. An interactive computer package could aid in this process. As discussed previously, such a package could be structured to provide respondents with the probability bounds for their future estimates based on the values previously specified. The program would also furnish the respondents with results computed from their estimates. Repeated exposure to such outputs could increase the respondents' experience with probabilistic relationships. Eventually, they might become proficient in making consistent probabilistic estimates.

However, aside from the previously mentioned methodological advantages, there does not appear to be any innate justification for pursuing this solution. The results of this study indicate that consistent responses can be obtained when using other than consistent probability values. If respondents do find probabilities difficult to work with, yet can produce consistent responses through some other thought process, it might be more appropriate to devise an

analytic procedure which taps expert opinions by using some other algorithm. In this case, the second interpretation given respondents' estimates might be worthy of increased attention and analysis.

2. Variations

The second interpretation given respondents' estimates suggests that individuals may be more comfortable working with a procedure which quantifies the variations produced by one variable interacting with another variable. The fact that the respondents appeared to think in terms of contingencies during event generation lends some support to this interpretation. If it can be determined that respondents are more comfortable when dealing with relative changes in events, a variation algorithm might be used to collect and manipulate their estimates.

Two measures have been developed which describe the relationships between variables (in this case events). Either, or both might be developed for use in cross-impact analysis. Turoff demonstrated the application of one variation measure, a correlation-based algorithm, in his cross-impact approach. The second variation measure, regression, might also be appropriate for use in cross-impact analysis.

Correlation coefficients range between minus and plus one. These boundaries could produce constraints similar to those encountered in using probabilities. However, using

a correlation algorithm would retain a certain ease of
manipulation. In addition, it would also be possible to
obtain an indication of estimator consistency.

This capability derives from the fact that under
this interpretation the cross-impact matrix would be
analogous to a correlation matrix. Consistency could
therefore be determined through analyzing the matrix entries.
A brief example, using a simplified correlation matrix, will
demonstrate this point

FIGURE 9

SIMPLIFIED CORRELATION MATRIX

EVENTS	A	B	C
A		↓	↑
B	↓		↑
C	↑	↑	

In a correlation matrix, if variable C increases
with an increase in variable A; then variable A must increase
with an increase in variable C. In other words, the matrix
entries above the diagonal must mirror the entries below
the diagonal to be consistent.

As a final consideration, the theory describing correlation coefficients is well enough developed that other analysis forms might be attempted. For example, the technique of path analysis could be developed as a method for tracing causal relationships. It might also be possible to trace logical structures on adjacency matrices using the principles developed by Harary [Ref. 42], and demonstrated by Bonham, et al., and Axelrod [Refs. 44, 45, and 43]. The correlation algorithm for cross-impacts might also be extended into a regression algorithm.

Regression coefficients represent the second variation measure which might be applied to cross-impact analysis. Because regression coefficients can range between plus and minus infinity, there would be no constraints imposed by bounding estimate values. However, using a regression algorithm could easily produce extremely large values, limiting the ease with which estimates could be manipulated. This fact is apparent upon recalling that some ordered outcome values computed in this study exceeded a value of thirty, and these were calculated using bounded estimates.

3. Summary

This study's results indicate that the method used in cross-event analysis to tap expert's opinions may be inappropriate. Two alternatives might be used to overcome this problem. The first possibility is to train respondents to think in probabilistic terms. The second is to develop

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another algorithm for interpreting and manipulating their estimates, possibly through using correlation or regression coefficients.

Choosing between these two alternatives cannot be attempted without further study. The primary focus for this additional study would be to empirically determine how people actually conceptualize relationships between events. Without an understanding of this crucial point, selection of a cross-impact algorithm can only be made arbitrarily. As a result, arbitrary estimate interpretation would preclude giving any confidence to specific results obtained from the analysis. Despite this problem, it is felt that the methodology has some potential as an alternative approach to decision analysis in socio-political applications.

C. CROSS-IMPACT ANALYSIS AS A DECISION-AID

Several advantages can be identified for the cross-impact technique when employed in assessing complex situations. First, its systematic approach assures that all problem elements identified as important are considered. The step by step procedure used can be easily traced to identify important elements in the problem situation, and to suggest areas requiring further study or close monitoring.

Secondly, the technique can serve as a valuable heuristic device. Its systematic approach forces respondents to care- fully evaluate each estimate (opinion) in conjunction with

their other estimates, and to consider the estimates'
implications in toto. This requires that the experts fully
and consistently formulate an underlying paridigm which can
aid an individual or organization in problem definition.
Thus, cross-impact analysis can be a useful modeling tool
and problem specification approach.

In addition, because the technique is time sensitive,
its results can be used to monitor problem development, or
at least the way in which the experts perceive that develop-
ment. Through monitoring the development of cross-impact
matrices it might also be possible to learn more about how
individual, group, and organizational thought processes
evolve in response to evolving situations, changing informa-
tion streams, and differing perceptions of problem compo-
nents. Thus, the technique's continued use might contribute
to an understanding of how individuals process information
(providing the data with which to resolve the question of
how respondent's estimates should be interpreted), and how
they perceive developing systems.

Even without having completed the designed implementa-
tion, because inconsistent ordered outcome probabilities
were obtained, it is still possible to make some observa-
tions regarding cross-impact analysis' utility as a decision-
aid. Obviously, there are several problems which must be
corrected before the technique can be applied in a "real-
world" analysis. Many problems encountered in the

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demonstration arose from a lack of experience in conducting subjective estimation sessions. Such "operator" problems included controlling the brainstorming session, and conducting the "event analysis." These problems were discussed, and solutions suggested in Chapter Four. None of the implementation problems appear to inhibit using the technique as much as the conceptual problem previously discussed.

The theory that interactions among discrete events can be quantified and systematically assessed seems to be an appropriate method for approaching complex, ill-defined problems. The technique's demonstrated computer adaptability enhances this attractiveness. Using a computer makes it possible to identify a large number of events for analysis. In some cases, it might be possible to practically specify the entire problem environment. Although this would require a very large number of estimates, they could be obtained and manipulated with the computer. However, until the conceptual question discussed in the previous section is resolved, cross-impact analysis remains a developmental methodology.

APPENDIX A

ESTIMATED RESPONSES

1. Candidate event set, probability and significance
   ratings, impact scores (standard deviations)

No.	Event Statement	Prob (S.D.)		Sig. (S.D.)		Imp. (S.D.)	
1	Kurds in Soviet Union revolt.	.115	.08	.48	.31	.62	.27
2	Egypt closes Suez Canal to Soviets.	.315	.12	.595	.22	.91	.17
3	United States deploys Carrier Task Force to Indian Ocean.	.755	.19	.62	.19	1.375	.31
4	Soviet Union initiates military alert along Chinese border.	.53	.28	.71	.25	1.24	.47
5	Soviet Union block-ades Gulf of Oman.	.275	.19	.725	.25	1.0	.32
6.	Soviet Union mines St. of Hormuz.	.185	.14	.77	.25	.955	.26
7	United States appeals to all parties to cease hostilities.	.805	.13	.18	.17	1.04	.17
8	United States offers to negotiate cease fire.	.64	.18	.48	.23	1.12	.27
9	United States evac-uates civilians from area.	.835	.10	.305	.14	1.135	.14
10	China ships arms to Baluchi rebels.	.575	.27	.575	.16	1.15	.39
11	India lends moral support to anti-Soviet forces.	.685	.14	.405	.22	1.09	.29

No.	Event Statement	Prob	(S.D.)	Sig.	(S.D.)	Imp.	(S.D.)
12	Chinese mobilize in Sinkiang.	.505	.25	.715	.20	1.22	.37
13	Iranian leftists sabotage oil fields.	.485	.16	.715	.16	1.20	.27
14	United States states it has no intention of becoming involved in the situation.	.275	.10	.675	.31	.945	.28
15	Leftists seize control in Iran.	.37	.14	.805	.14	1.175	.13
16	United Nations meets to discuss the problem.	.885	.08	.195	.14	1.08	.17
17	Iranian and Soviet units skirmish in area around Afghanistan.	.485	.25	.625	.20	1.12	.37
18	Iranian government clamps down on leftists.	.71	.18	.375	.13	1.09	.13
19	Civil War breaks out in Iran.	.535	.24	.595	.24	1.22	.18
20	United States convoys oil shipments with Naval units.	.385	.25	.570	.22	.955	.42
21	Ayatolla Khomeini calls for Jihad.	.48	.25	.545	.27	1.03	.27
22	Soviet backed Afghani forces subjugate Baluchistan.	.595	.15	.885	.14	1.48	.19
23	Soviet Union airlifts supplies to Afghanistan.	.72	.20	.65	.17	1.37	.34
24	United States sends aid to Pakistan.	.465	.16	.60	.12	1.07	.24
25	United States sends aid to Iran.	.425	.18	.58	.21	1.01	.37

No.	Event Statement	Prob	(S.D.)	Sig.	(S.D.)	Imp.	(S.D.)
26	United States deploys troops to Saudi Arabia.	.255	.13	.625	.17	.88	.22
27	United States deploys an F-15 squadron to Saudi Arabia.	.475	.23	.425	.2	.90	.40
28	Soviet Union builds up its Indian Ocean squadron.	.795	.19	.625	.13	1.42	.28
29	Soviet Union harrasses oil tankers.	.25	.20	.685	.25	.935	.30

2. Ranking by Impact (top ten)

	All Events		Response Events
No.	Short Name	No.	Short Name
22*	S.U./Afghan forces gain control	3*	U.S. deploys CTF
28*	S.U. builds up I.O. sqdrn.	9*	U.S. evacuates civilians
3	U.S. deploys CTF	8*	U.S. offers negotiation
23*	S.U. supplies Afghanistan	7	U.S. appeals for cease fire
4	S.U. mobilizes Chinese border	24	Aid Pakistan
19	Civil War in Iran	20	Convoy oil
12	Chinese mobilize in Sinkiang	25	Aid Iran
13	Leftists sabotage oil in Iran	14	Non-involvement
15	Leftist coup in Iran	27	F-15's to Saudi Arabia
10	China arms Baluchis	26	Troops to Saudi Arabia

(* indicates events chosen for analysis)

3. Estimated interactions by Event Pair

Event Pair (i,j) P(i) P(j)	C_1 $(i\|j)$	C_2 $(j\|i)$	C_3 $(i\|\bar{j})$	C_4 $(j\|\bar{i})$	C_5 $(i_f\|i\&j)$
(22,28) .6 .8	.66	.83	.56	.80	.23
(22,23) .6 .72	.72	.80	.54	.70	.24

Event Pair (i,j) P(i)|P(j)	C_1 (i|j)	C_2 (j|i)	C_3 (i|$\bar{j}$)	C_4 (j|$\bar{i}$)	C_5 (i_f|i&j)
(22,3) .6|.76	.57	.85	.67	.76	.51
(22,9) .6|.84	.68	.92	.59	.83	.51
(22,8) .8|.72	.58	.61	.65	.68	.32
(28,23) .8|.76	.82	.77	.79	.72	.56
(28,3) .8|.84	.86	.87	.80	.75	.61
(28,9) .8|.64	.81	.86	.80	.84	.77
(28,8) .72|.76	.8	.66	.81	.66	.74
(23,3) .72|.84	.75	.81	.73	.75	.56
(23,9) .72|.64	.73	.86	.72	.83	.78
(23,8) .76|.84	.73	.70	.73	.64	.69
(23,9) .76|.84	.79	.86	.78	.83	.80
(3,8) .76|.84	.77	.65	.77	.68	.52
(9,8) .84|.64	.82	.66	.85	.67	.35

APPENDIX B

CALCULATED RESPONSES

1. Resultant ordered outcome probabilities by Event Pair

Event Pair (i,j)	P_1 (i,j)	P_2 (i,$\bar{j}$)	P_3 ($\bar{i}$,j)	P_4 ($\bar{i}$,$\bar{j}$)	P_5 (j,i)	P_6 (j,$\bar{i}$)	P_7 ($\bar{j}$,i)	P_8 ($\bar{j}$,$\bar{i}$)
(22,28)	2.6	.53	-9.7	-2.4	8.7	4.5	39.3	30.9
(22,23)	5.1	.53	-15.3	-7.4	16.3	6.3	-66.6	-56.8
(22,3)	1.6	.28	-2.5	-.78	1.5	1.2	-2.7	-1.3
(22,9)	-1.5	-.13	-.6	-.12	-1.5	-.69	3.6	2.5
(22,8)	4.5	2.9	-18.3	-8.6	6.1	4.5	-22.4	-12.1
(28,23)	1.3	.38	-1.3	-.51	1.0	.22	-1.3	-.35
(28,3)	1.2	.12	-1.2	-.39	.75	.12	-.55	-.14
(28,9)	1.5	.24	-.55	-.10	.44	.10	.16	.04
(28,8)	-.16	-.1	-.70	-.36	-.06	-.02	.91	.21
(23,3)	1.4	.32	-1.4	-.47	1.1	.37	-1.5	-.55
(23,9)	1.2	.19	-.57	-.12	.34	.13	.23	.09
(23,8)	2.3	.97	-1.2	-.67	1.0	.38	-1.2	-.44
(3,9)	1.1	.18	-.48	-.10	.28	.07	.37	.08
(3,8)	1.9	1.0	1.8	-.85	1.7	.50	-3.4	-1.0
(9,8)	1.2	.63	-2.7	-1.3	2.3	.50	-6.8	-1.2

2. Probability rankings by Event Pair

(22,28) Or: Sov/Afg. forces gain control of Baluchistan,
              Soviet Union builds up I.O. squadron

	Outcome Ranking	Meaning	Pairing by Opp. Cause
1.	P_7	$(\bar{j},i)$	
2.	P_8	$(\bar{j},\bar{i})$	
3.	P_5	(j,i)	
4.	P_6	$(j,\bar{i})$	
5.	P_1	(i,j)	
6.	P_2	$(i,\bar{j})$	
7.	P_4	$(\bar{i},\bar{j})$	
8.	P_3	$(\bar{i},j)$	

Evaluation: Inconsistent

(22,23) Or: Sov/Afg. forces gain control of Baluchistan,
              Soviets airlift supplies to Afghanistan

	Outcome Ranking	Meaning	Pairing by Opp. Cause
1.	P_5	(j,i)	
2.	P_6	$(j,\bar{i})$	
3.	P_1	(i,j)	
4.	P_2	$(i,\bar{j})$	
5.	P_4	$(\bar{i},\bar{j})$	
6.	P_3	$(\bar{i},j)$	
7.	P_8	$(\bar{j},\bar{i})$	
8.	P_7	$(\bar{j},i)$	

Evaluation: Consistent

(22,3) Or: Sov/Afg. forces gain control of Baluchistan,
            U.S. deploys CTF to I.O.

Outcome Ranking	Meaning	Pairing by Opp. Cause
1. P_1	(i,j)	
2. P_5	(j,i)	
3. P_6	$(j,\bar{i})$	
4. P_2	$(i,\bar{j})$	
5. P_4	$(\bar{i},\bar{j})$	
6. P_8	$(\bar{j},\bar{i})$	
7. P_3	$(\bar{i},j)$	
8. P_7	$(\bar{j},i)$	$|\text{Dif.}| = .2$

Evaluation: Apparently Inconsistent, however, value difference
             from rank 7 to rank 8 is only .2; therefore,
             possibly consistent

(22,9) Or: Sov/Afg. forces gain control of Baluchistan,
            U.S. evacuates civilians from area

Outcome Ranking	Meaning	Pairing by Opp. Cause
1. P_7	$(\bar{j},i)$	
2. P_8	$(\bar{j},\bar{i})$	
3. P_4	$(\bar{i},\bar{j})$	
4. P_2	$(i,\bar{j})$	
5. P_3	$(\bar{i},j)$	
6. P_6	$(j,\bar{i})$	
7. P_5	(j,i)	
8. P_1	(i,j)	

Evaluation: Inconsistent

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(22,8) Or: Sov/Afg. forces gain control of Baluchistan,
           U.S. offers to negotiate a cease-fire

Outcome Ranking	Meaning	Pairing by Opp. Cause
1. P_5	(j,i)	
2. P_1	(i,j)	
3. P_6	$(j,\bar{i})$	
4. P_2	$(i,\bar{j})$	
5. P_4	$(\bar{i},\bar{j})$	
6. P_8	$(\bar{j},\bar{i})$	
7. P_3	$(\bar{i},j)$	
8. P_7	$(\bar{j},i)$	
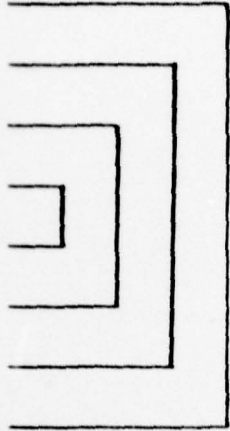
Evaluation: Consistent

(28,23) Or: S.U. builds up I.O. squadron,
            Soviets airlift supplies to Afghanistan

Outcome Ranking	Meaning	Pairing by Opp. Cause
1. P_1	(i,j)	
2. P_5	$(j,\bar{i})$	
3. P_2	$(i,\bar{j})$	
4. P_6	$(\bar{j},i)$	
5. P_8	$(\bar{j},\bar{i})$	
6. P_4	$(\bar{i},\bar{j})$	
7.		
TIE P_3 & P_7	$(\bar{i},j)$ & $(\bar{j},i)$	TIE
8.		
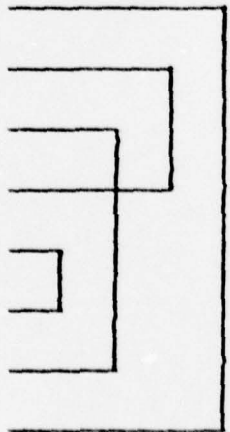
Evaluation: Consistent because $P_3 = P_7$.

(28,3) Or: S.U. builds up I.O. squadron
            U.S. deploys CTF to I.O.

Outcome Ranking		Meaning	Pairing by Opp. Cause
1.	P_1	(i,j)	
2.	P_5	(j,i)	
3.	TIE P_2 & P_6	$(i,\bar{j})$ & $(j,\bar{i})$	TIE
4.			
5.	P_8	$(\bar{j},\bar{i})$	
6.	P_4	$(\bar{i},\bar{j})$	
7.	P_7	$(\bar{j},i)$	
8.	P_3	$(\bar{i},j)$	

Evaluation: Consistent due to tie as in previous case.

(28,9) Or: S.U. builds up I.O. squadron,
            U.S. evaculates civilians from area

Outcome Ranking		Meaning	Pairing by Opp. Cause
1.	P_1	(i,j)	
2.	P_5	(j,i)	
3.	P_2	$(i,\bar{j})$	
4.	P_7	$(\bar{j},i)$	
5.	P_6	$(j,\bar{i})$	
6.	P_8	$(\bar{j},\bar{i})$	
7.	P_4	$(\bar{i},\bar{j})$	
8.	P_3	$(\bar{i},j)$	

Evaluation: Inconsistent

(28,8) Or: S.U. builds up I.O. squadron
           U.S. offers to negotiate a cease-fire

	Outcome Ranking	Meaning	Pairing by Opp. Cause
1.	P_7	$(\bar{j},i)$	
2.	P_8	$(\bar{j},\bar{i})$	
3.	P_6	$(j,\bar{i})$	
4.	P_5	(j,i)	
5.	P_2	$(i,\bar{j})$	
6.	P_1	(i,j)	
7.	P_4	$(\bar{i},\bar{j})$	
8.	P_3	$(\bar{i},j)$	

Evaluation: Inconsistent

(23,3) Or: S.U. airlifts supplies to Afghanistan,
           U.S. deploys CTF to I.O.

	Outcome Ranking	Meaning	Pairing by Opp. Cause
1.	P_1	(i,j)	
2.	P_5	(j,i)	
3.	P_6	$(j,\bar{i})$	
4.	P_2	$(i,\bar{j})$	
5.	P_4	$(\bar{i},\bar{j})$	
6.	P_8	$(\bar{j},\bar{i})$	
7.	P_3	$(\bar{i},j)$	
8.	P_7	$(\bar{j},i)$	

$|\text{Dif.}| = .07$

Evaluation: Apparently Inconsistent, however, value difference
            from rank 7 to rank 8 is only .07, therefore,
            Consistent.

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(23,9) Or: S.U. airlifts supplies to Afghanistan,
U.S. evacuates civilians from area

Outcome	Ranking	Meaning	Pairing by Opp. Cause
1.	P_1	(i,j)	
2.	P_5	(j,i)	
3.	P_7	($\bar{j}$,i)	
4.	P_2	(i,$\bar{j}$)	
5.	P_6	(j,$\bar{i}$)	
6.	P_8	($\bar{j}$,$\bar{i}$)	
7.	P_4	($\bar{i}$,$\bar{j}$)	
8.	P_3	($\bar{i}$,j)	

Evaluation: Inconsistent

(23,8) Or: S.U. airlifts supplies to Afghanistan,
U.S. offers to negotiate a cease-fire

Outcome	Ranking	Meaning	Pairing by Opp. Cause
1.	P_1	(i,j)	
2.	P_5	(j,i)	
3.	P_2	(i,$\bar{j}$)	
4.	P_6	(j,$\bar{i}$)	
5.	P_8	($\bar{j}$,$\bar{i}$)	
6.	P_4	($\bar{i}$,$\bar{j}$)	
7.	P_3	($\bar{i}$,j)	
8.	P_7	($\bar{j}$,i)	|Dif.| = .01

Evaluation: Apparently Inconsistent, however, value
difference between rank 7 and rank 8 is only
.01, therefore, Consistent.

(3,9) Or: U.S. deploys CTF to I.O.
            U.S. evacuates civilians from area

Outcome	Ranking	Meaning	Pairing by Opp. Cause
1.	P_1	(i,j)	
2.	P_7	$(\bar{j},i)$	
3.	P_5	(j,i)	
4.	P_2	$(i,\bar{j})$	
5.	P_8	$(\bar{j},\bar{i})$	
6.	P_6	$(j,\bar{i})$	
7.	P_4	$(\bar{i},\bar{j})$	
8.	P_3	$(\bar{i},j)$	

Evaluation: Inconsistent.

(3,8) Or: U.S. deploys CTF to I.O.,
            U.S. offers to negotiate a cease-fire

Outcome	Ranking	Meaning	Pairing by Opp. Cause
1.	P_1	(i,j)	
2.	P_3	$(\bar{i},j)$	
3.	P_5	(j,i)	
4.	P_2	$(i,\bar{j})$	
5.	P_6	$(j,\bar{i})$	
6.	P_4	$(\bar{i},\bar{j})$	
7.	P_8	$(\bar{j},\bar{i})$	
8.	P_7	$(\bar{j},i)$	

Evaluation: Inconsistent.

9,8 Or: U.S. evacuates civilians from area,
          U.S. offers to negotiate a cease-fire

Outcome	Ranking	Meaning	Pairing by Opp. Cause
1.	P_5	(j,i)	
2.	P_1	(i,j)	
3.	P_2	$(i,\bar{j})$	
4.	P_6	$(j,\bar{i})$	
5.	P_8	$(\bar{j},\bar{i})$	
6.	P_4	$(\bar{i},\bar{j})$	
7.	P_3	$(\bar{i},j)$	
8.	P_7	$(\bar{j},i)$	

Evaluation: Consistent

3. Summary of Results

Case	Pair	Consistent	Order
1	(22,28)	NO	7, 8, 5, 6, 1, 2, 4, 3
2	(22,23)	YES	5, 6, 1, 2, 4, 3, 8, 7
3	(22,3)	NO	1, 5, 6, 2, 4, 8, 3, 7
4	(22,9)	NO	7, 8, 4, 2, 3, 6, 5, 1
5	(22,8)	YES	5, 1, 6, 2, 4, 8, 3, 7
6	(28,23)	YES	1, 5, 2, 6, 8, 4, 7, 3
7	(28,3)	YES	1, 5, 2, 6, 8, 4, 7, 3
8	(28,9)	NO	1, 5, 2, 7, 6, 8, 4, 3
9	(28,8)	NO	7, 8, 6, 5, 2, 1, 4, 3
10	(23,3)	YES	1, 5, 6, 2, 4, 8, 7, 3
11	(23,9)	NO	1, 5, 7, 2, 6, 8, 4, 3
12	(23,8)	YES	1, 5, 2, 6, 8, 4, 7, 3
13	(3,9)	NO	1, 7, 5, 2, 8, 6, 4, 3
14	(3,8)	NO	1, 3, 5, 2, 6, 4, 8, 7
15	(9,8)	YES	5, 1, 2, 6, 8, 4, 3, 7

All inconsistent outcome orders are unique.
The seven consistent outcome patterns occur in 5 sets.

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